Glass Thick-GEM

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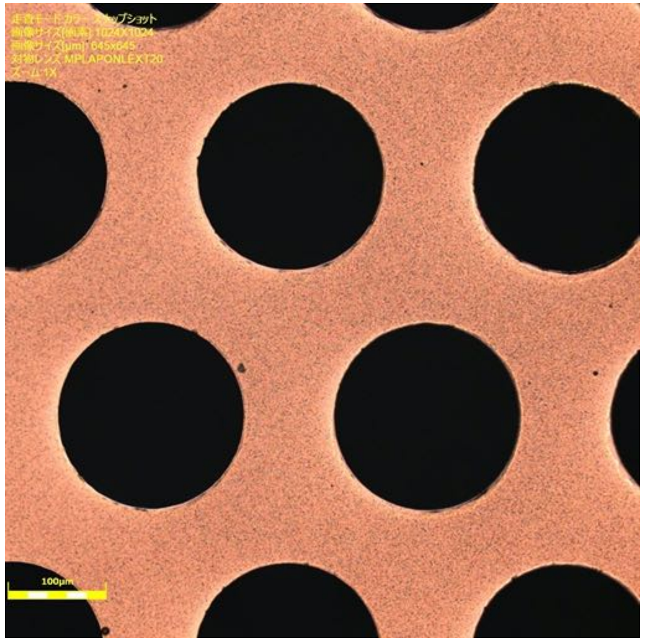
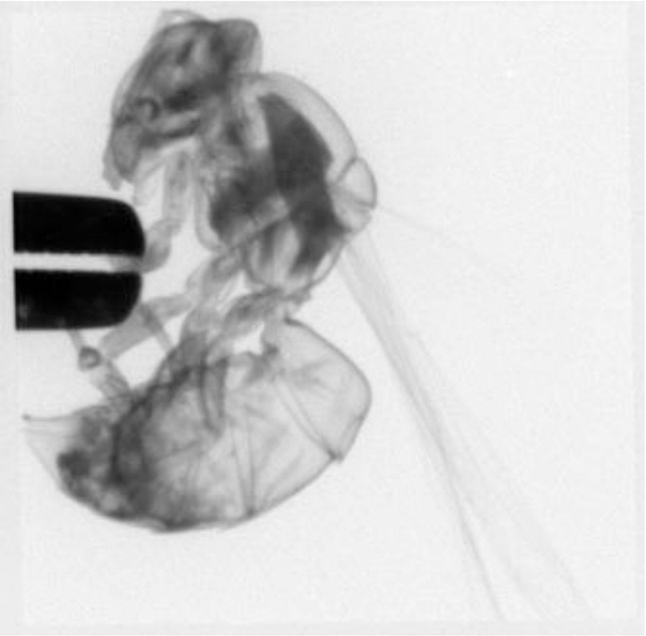
Outline

1. Glass GEM fabrication process
2. Comparison with PEG3 and PEG3C
3. Applications
   a. X-ray imaging with optical readout
   b. Hadron Therapy
   c. Neutron Bragg-Edge Imaging
4. Summary





Contents

Motivation: To develop a portable & versatile imaging detector.

→ Sealed operation is essential

Why sealed operation ?

1. Use of rare and expensive gases

→ ^{3}He for neutron detection, Xenon for higher energy X-ray.

2. High pressure operation (or Low)

→ Higher detection rate, smaller diffusion of electrons.

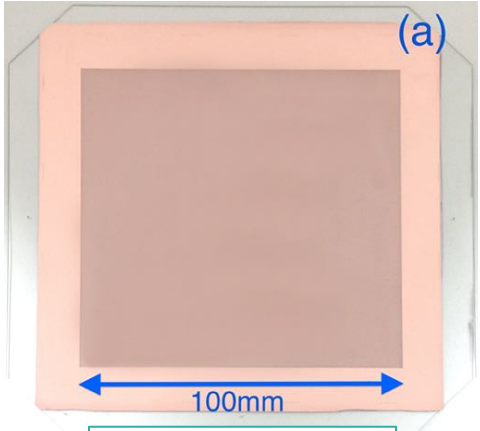
3. Make a compact detector system

→ Remove gas flow components, gas cylinder, purification system

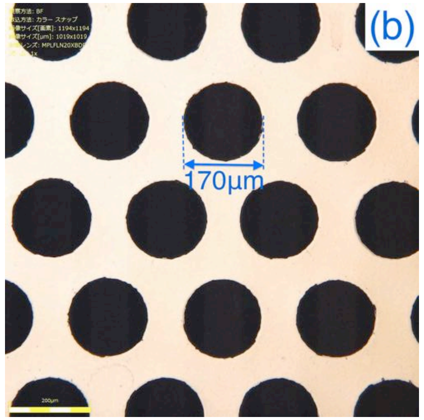
Non-outgassing MPGD is ideal

→ **Glass gas electron multiplier**

1. Background & Motivation - X-ray imaging with Glass GEM



100mm□Glass GEM



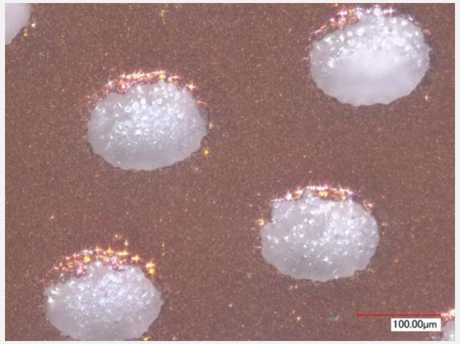
Micrograph of Glass GEM

Cross section of the Glass GEM’s hole

- Thick GEM made with glass substrate[1, 2]
- Why Glass GEM?
  - **Robust –** tolerant against discharges
  - **Rigid –** self-supporting structure, easy to handle
  - **Wet-etching –** uniform & Cylindrical Hole
  - **High gas gain –** up to 90,000 with single Glass GEM[3]
  - **High spatial resolution –** minimize charge spread

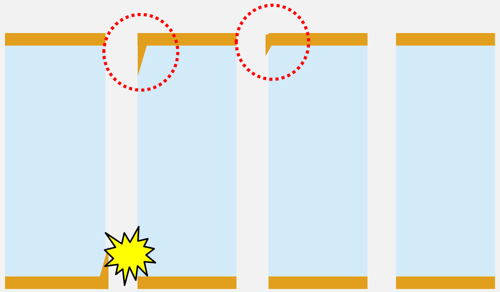
[1] T. Fujiwara, et al., MPGD2011
[2] H. Takahashi, et al., NIM A, vol. 724, pp. 1–4, (2013)
[3] T. Fujiwara, et al., JINST, vol. 9, pp. 11007 - 11007, (2014)

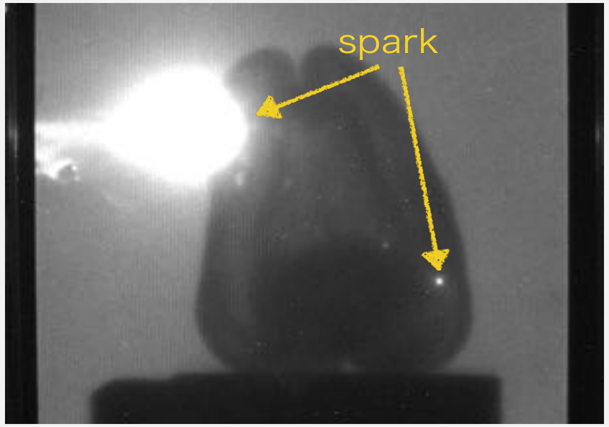
An issue…



Micrograph of Glass GEM in early days

Metals inside via causes sparks





Discharges ruins the electrodes

2. Glass GEM fabrication process at AIST

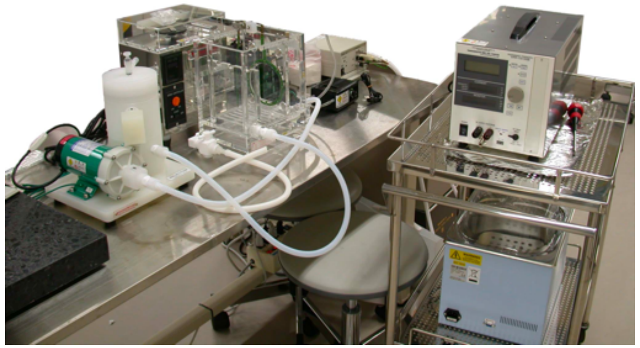
UV exposure machine

Etching machine

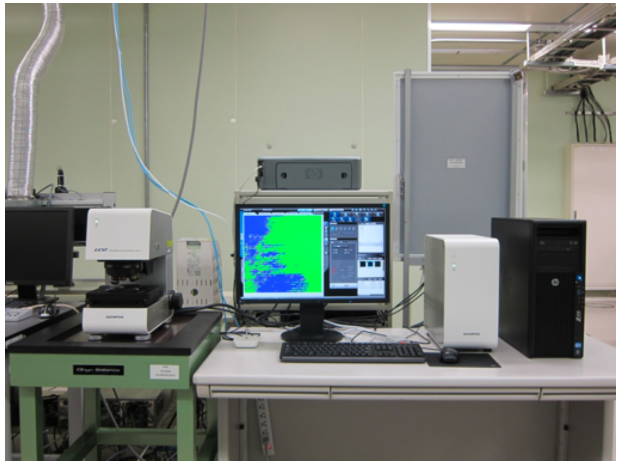
DC sputtering machine for Cr

DC sputtering machine for Cu

Polishing machine



Plating machine

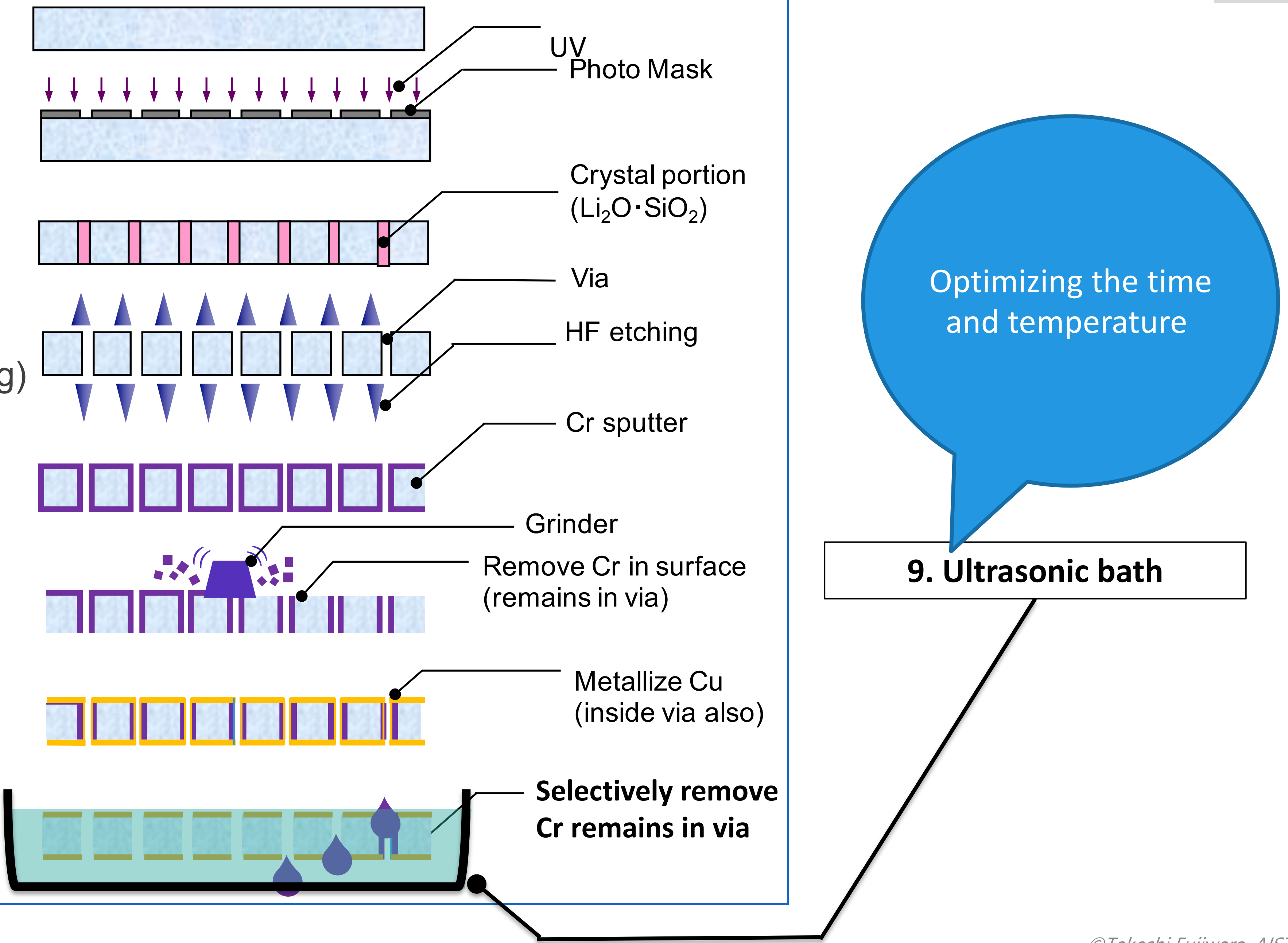


Laser microscope

Approximately 80% of the fabrication process are done in AIST (Many thanks to T. Fushie)

2. Glass GEM fabrication process

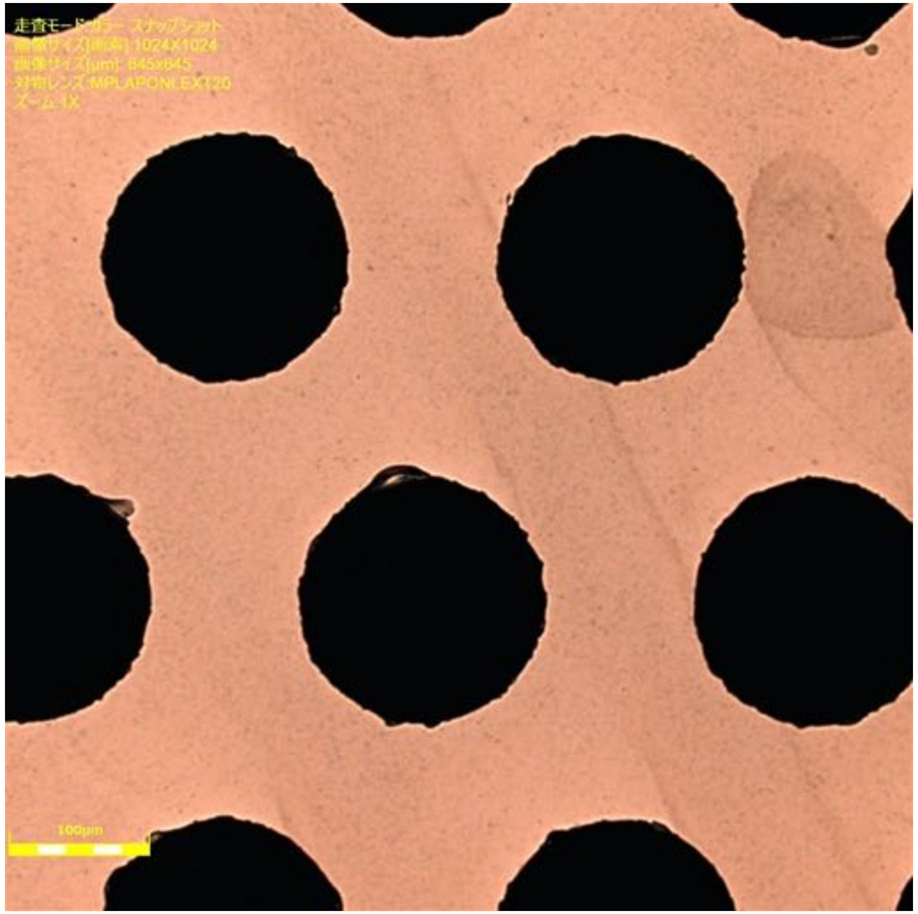
1. Glass Substrate
2. UV exposure (1st_exp)
3. Crystal formation
   (heat treatment)
4. Via etching
   (Hydrogen Fluoride wet etching)
5. Poison Metallization
6. Remove metal except in via
7. Metallization process II (Cu)
8. Selectively etch metal in via



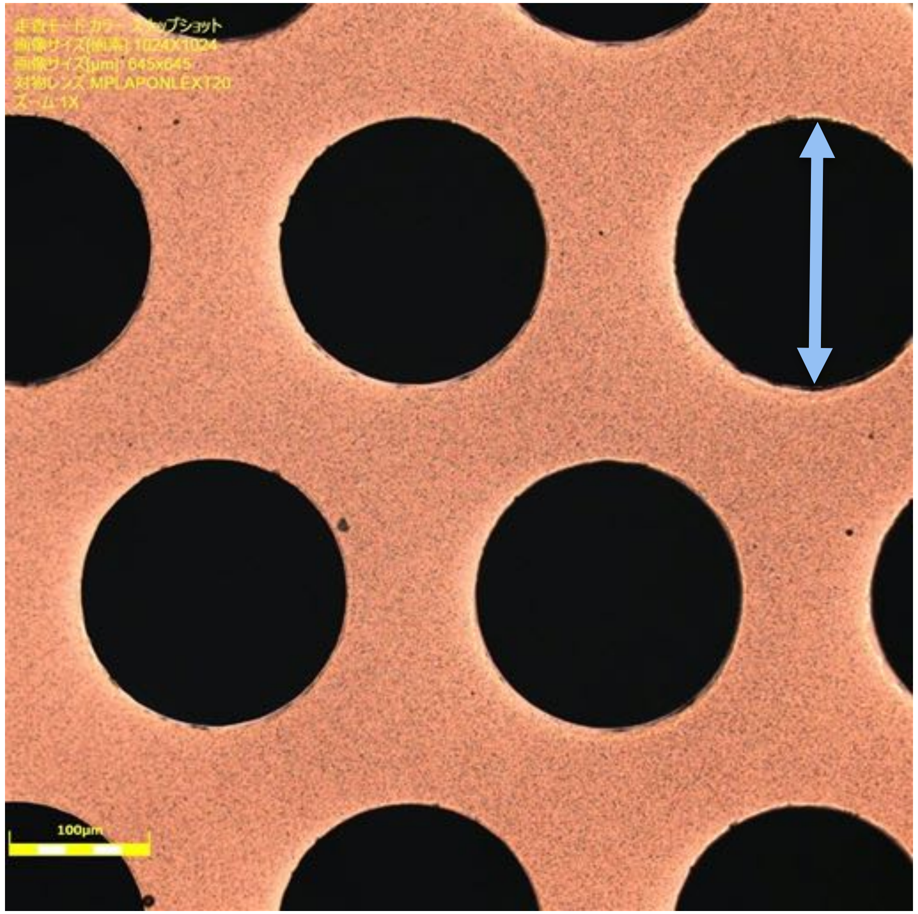
[4] T. Fujiwara, et al., NIM A, 878 (2018)

2. The new Glass GEM fabrication process at AIST

Old process

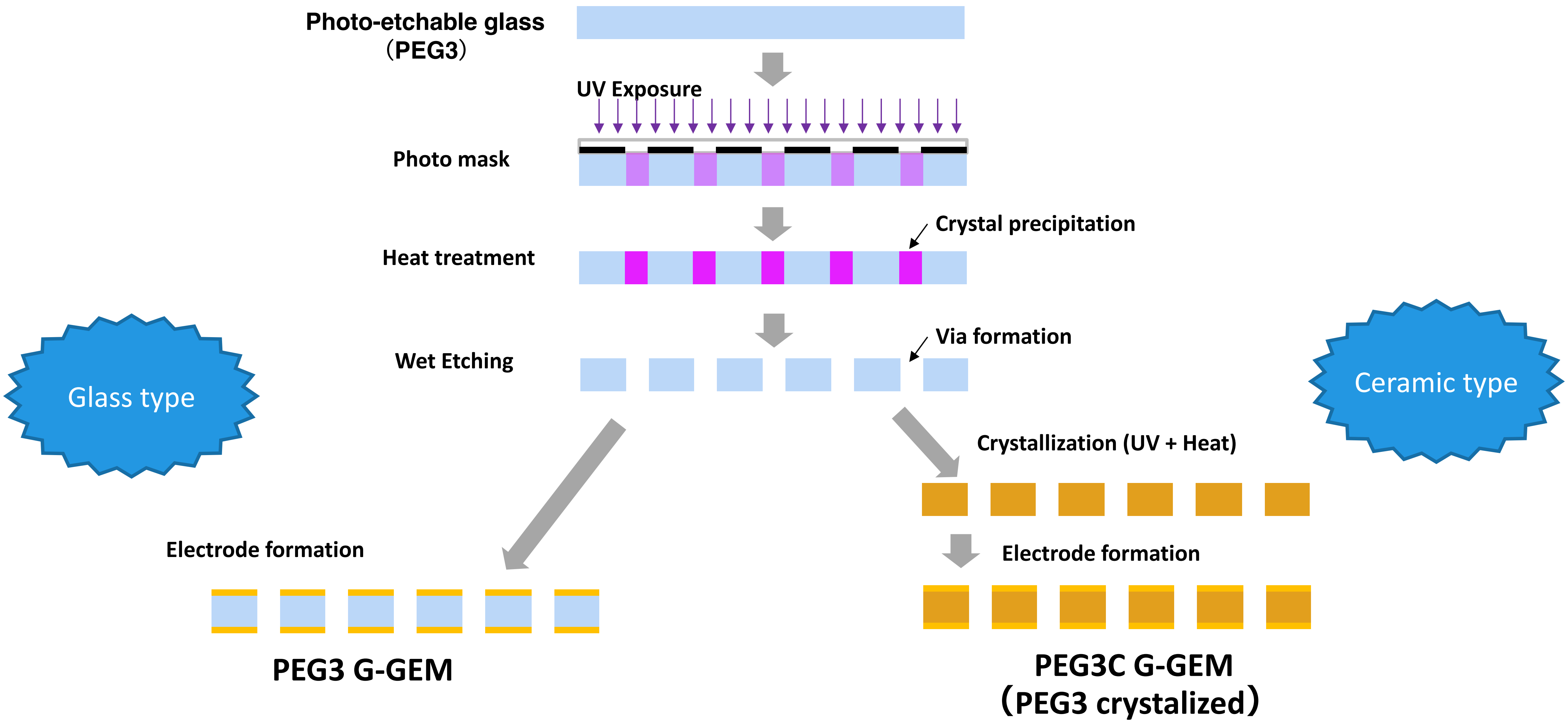


The New process



Smooth electrode: Uniformity of the electric field improves, and the GEM's stability improves

G-GEM fabrication



Michael Kösters, et al., “Holography in commercially available photoetchable glasses”, 2005 Optical Society of America, OCIS codes: 090.7330, 090.2900.

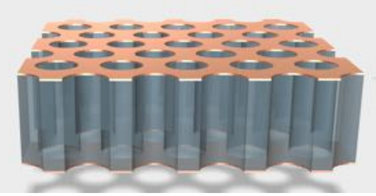
2. Comparison (PEG3 and PEG3C G-GEM)

Parameter comparison - Kapton, PEG3, PEG3C

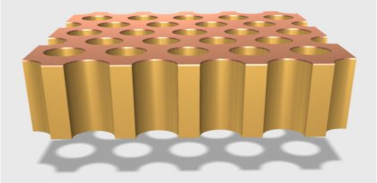
	Unit	Kapton	PEG3	PEG3C
Volume Resistivity	Ω・cm	~10^{18}	**8.5×10^{12}**	**4.5×10^{14}**
Bending Stress	MPa		**>65**	**>150**
Young's modulus	Gpa	18.6	79.7	90.3
Relative Permittivity		3.55	6.28	5.26
Heat conductivity	W/mK	~0.3	0.795	2.72
Thickness	um		400 – 800	100 - 700

Glass type

Ceramic type



PEG3 G-GEM



PEG3C G-GEM

PEG3

Low resistivity (8.5×10^{12}Ωcm)

= Less charge-up on the glass substrate

= Stable operation is expected even with high rate.

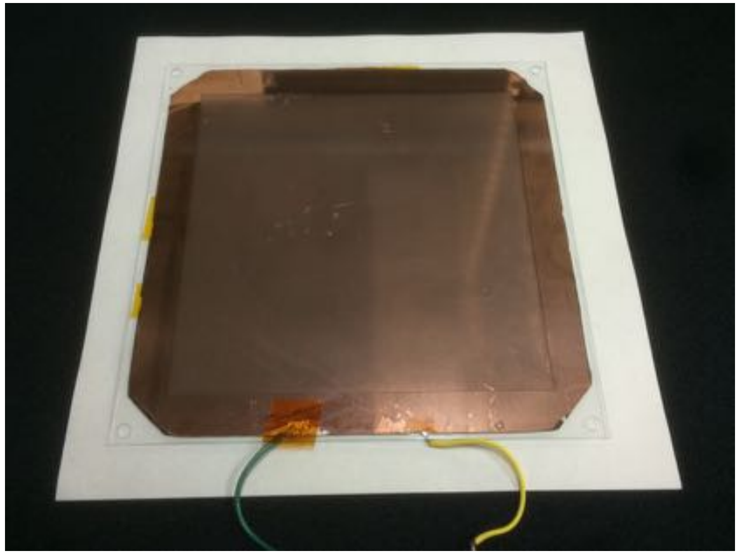
PEG3C=Crystalized PEG3

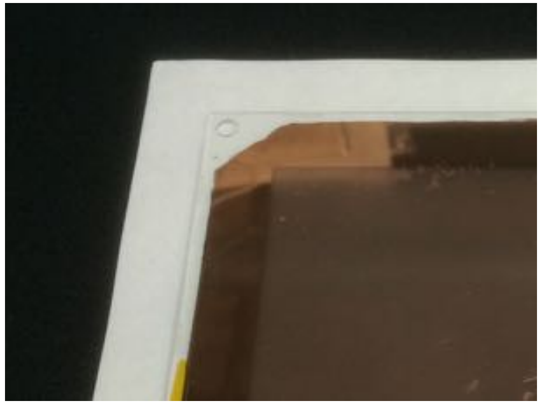
- Higher resistivity than PEG3 (may lead to more charge-up.)
- **Higher mechanical robustness increases available detector designs.** **e.g. thinner substrate** (~100 μm) → Thinner substrate = Less charge-up.
- Chemically stable, more phobic to moisture than PEG3.

2. G-GEM with PEG3/PEG3C

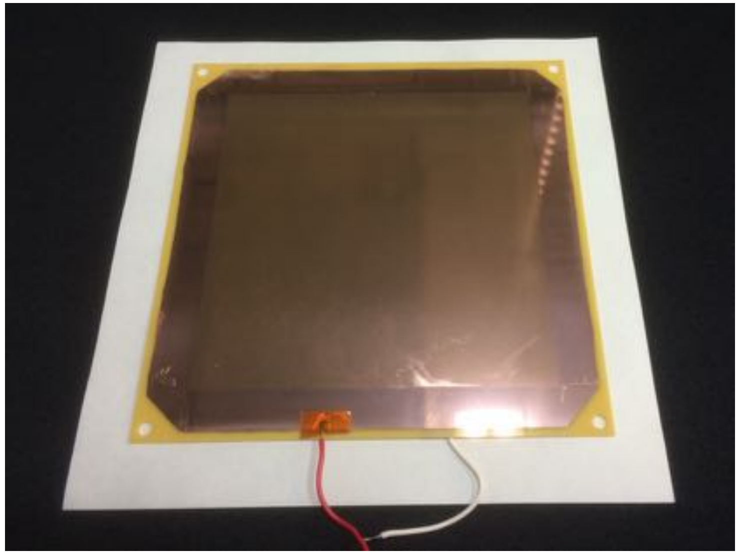
PEG3 **PEG3C**

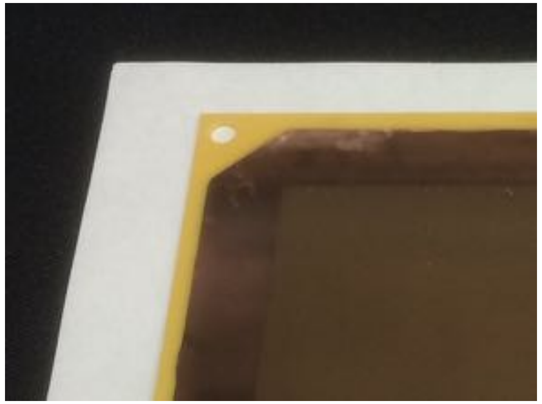
Glass type





Ceramic type

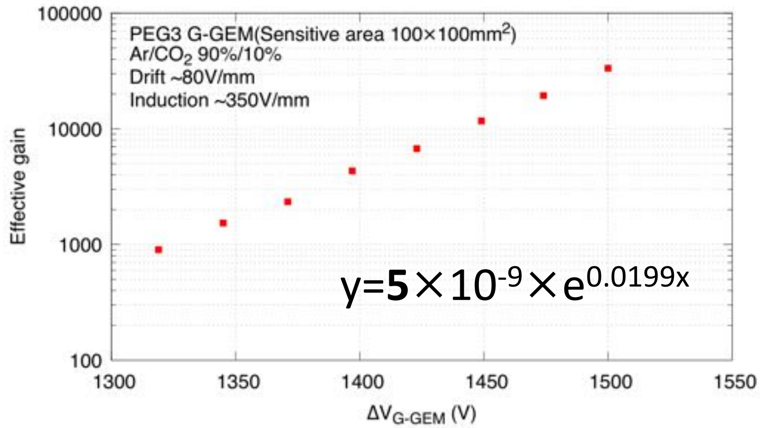




G-GEM Photos (10×10 cm^2)

2. G-GEM with PEG3/PEG3C

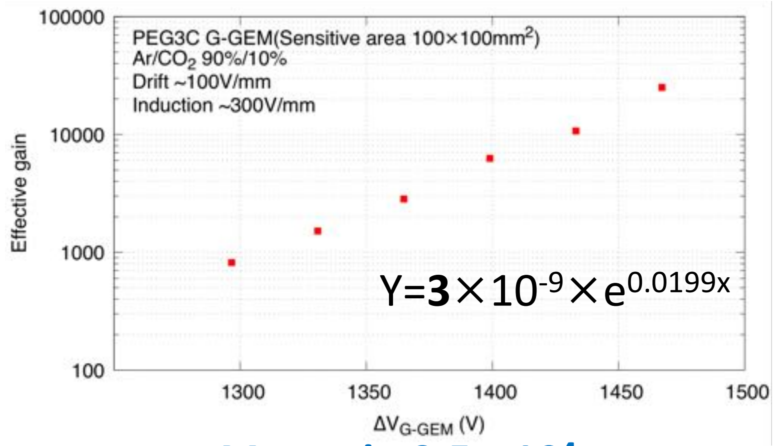
PEG3



$y=\mathbf{5}\times10^{-9}\times e^{0.0199x}$

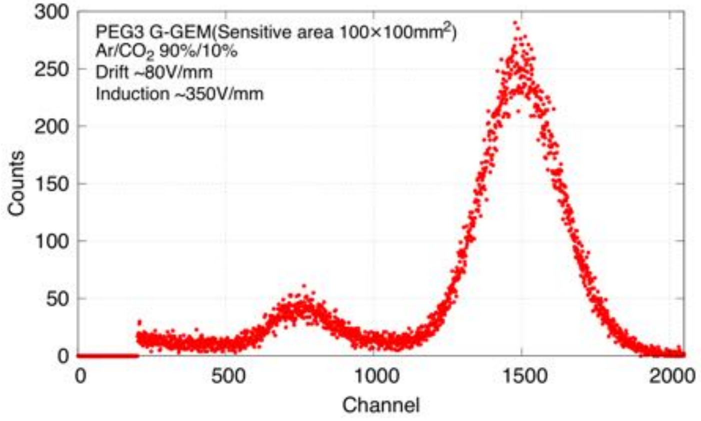
Max gain 3.3×10^4

PEG3C

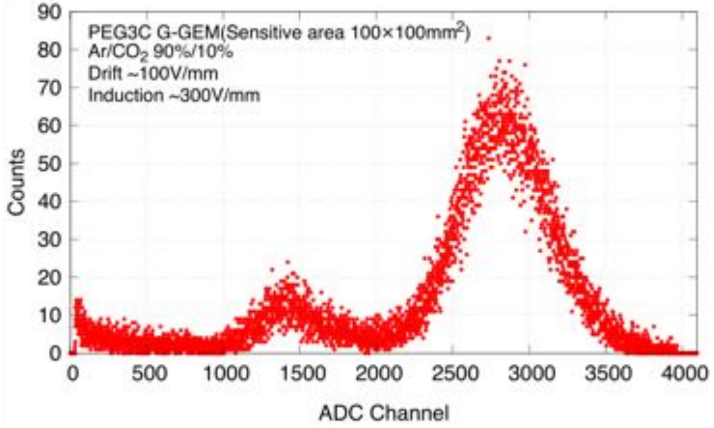


$Y=\mathbf{3}\times10^{-9}\times e^{0.0199x}$

Max gain 2.5×10^4



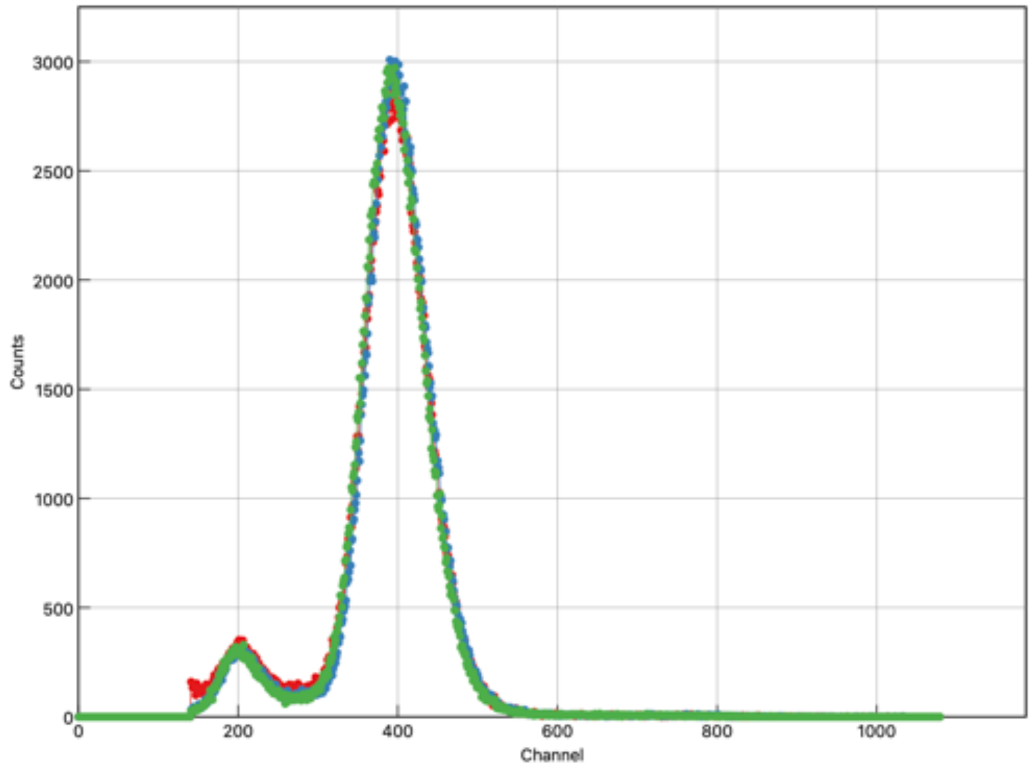
22.2% FWHM @Gain~10^4



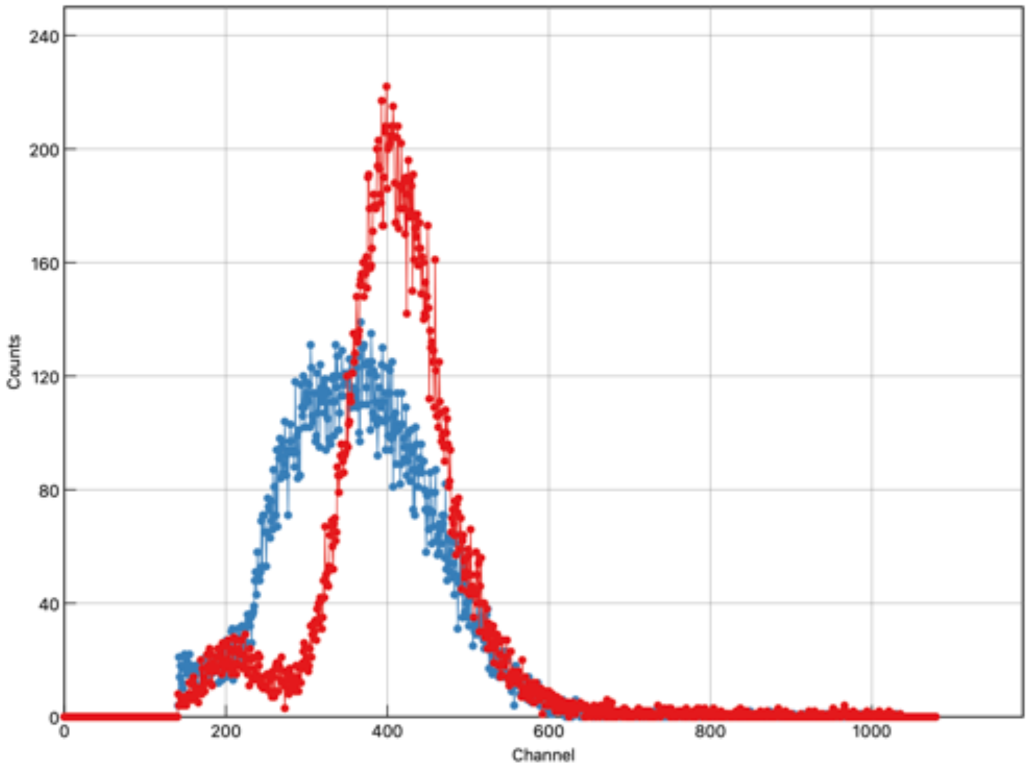
25.7% FWHM @Gain~10^4

PEG3 has higher gas gain and better energy resolution

2. G-GEM with PEG3/PEG3C



PEG3



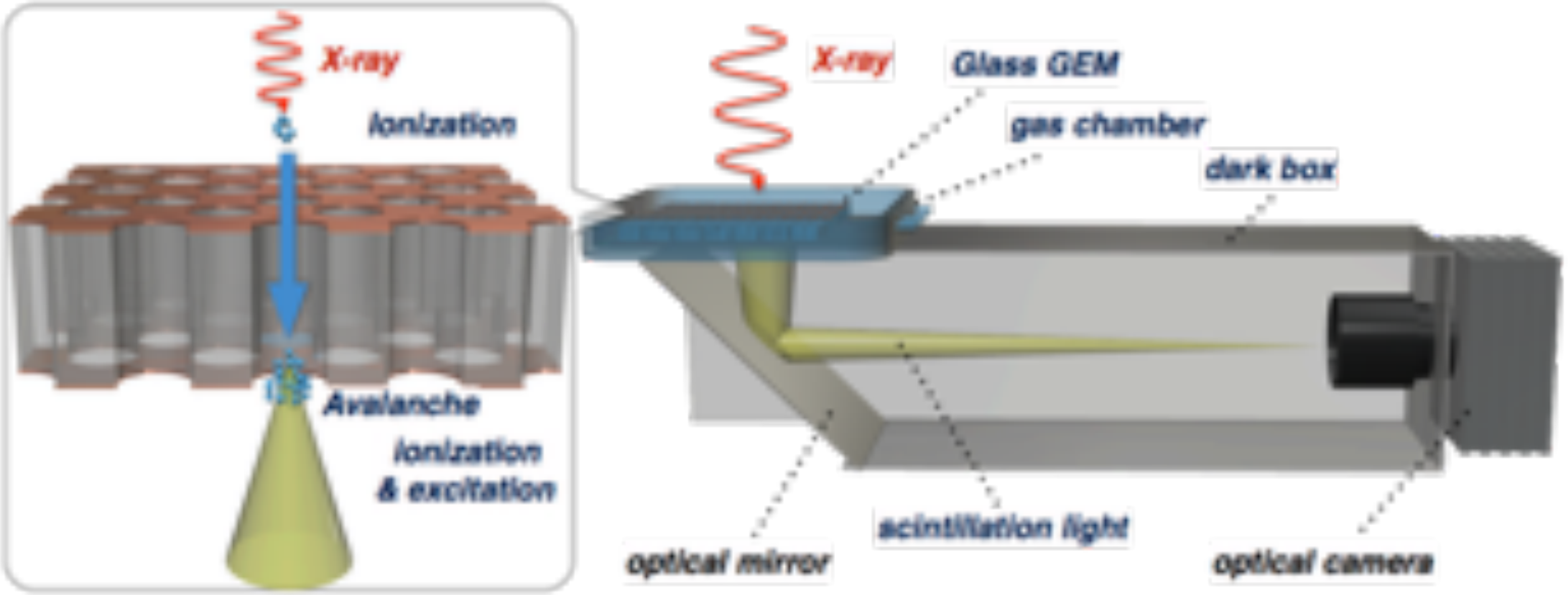
PEG3C

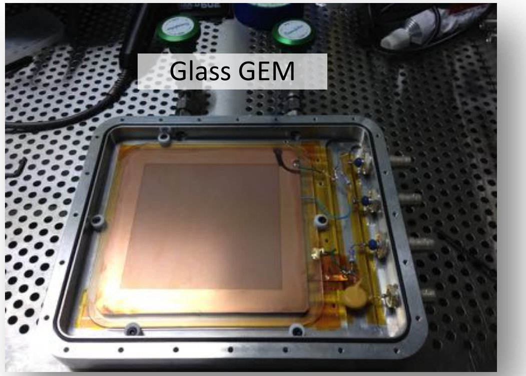
PEG3 was stable during high count rate measurement

Gain decrease due to the charge-up

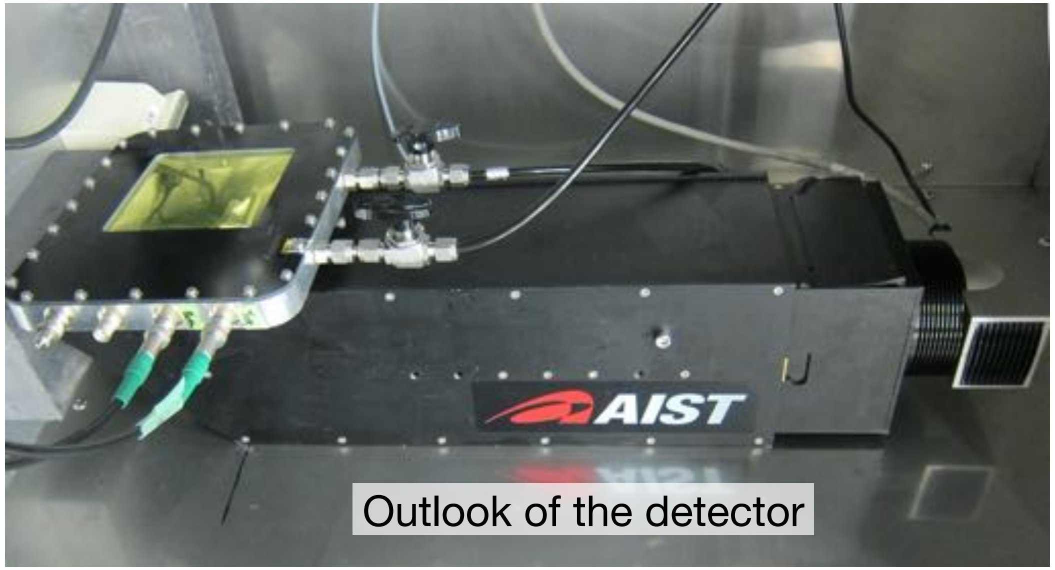
X-ray imaging with optical readout

3. Optical readout Glass GEM[8,9]





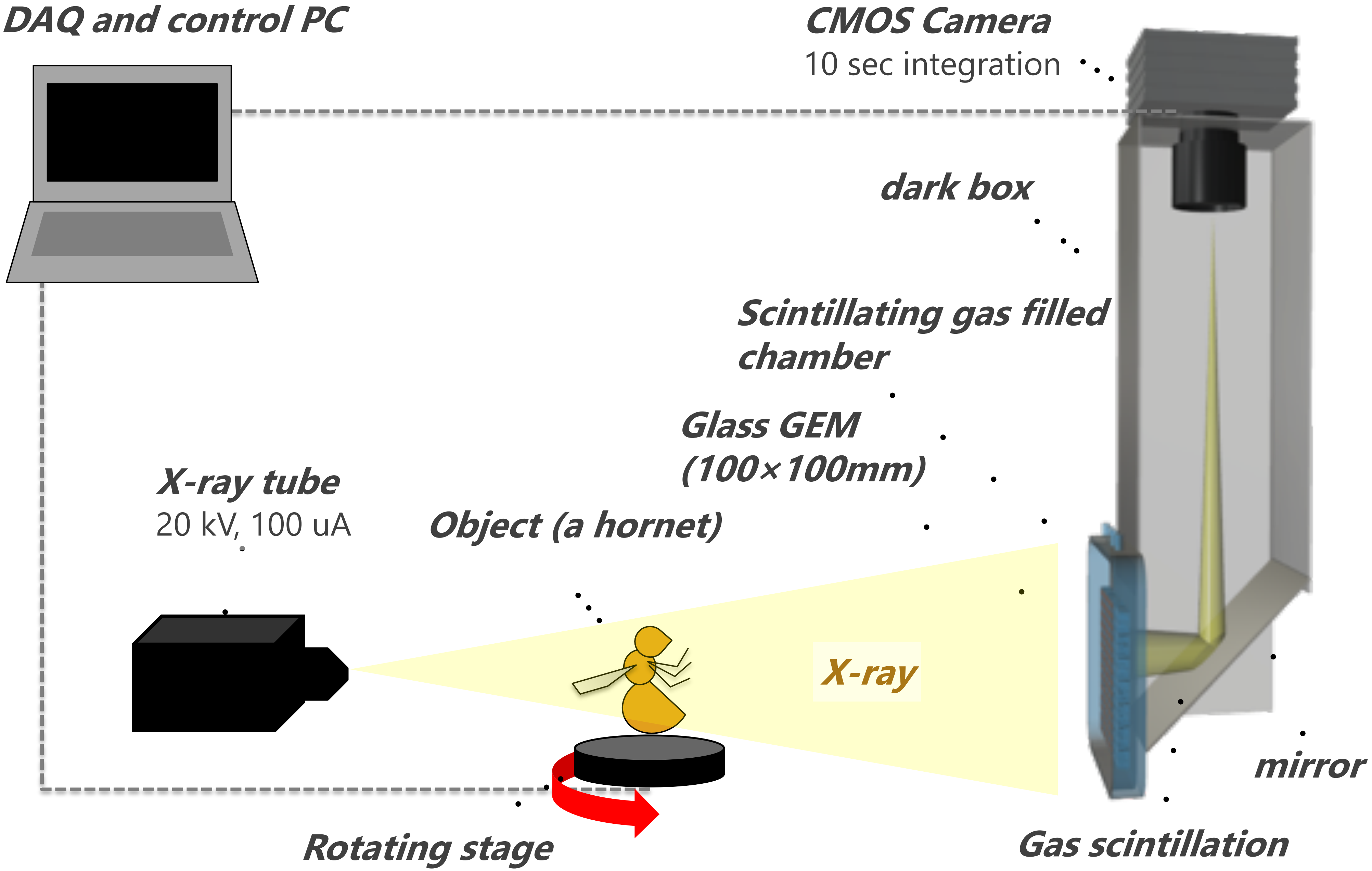
- Glass GEM × scintillation gas × mirror × optical camera
- Convert radiation into visible light
- Optical mirror to prevent the CMOS from irradiated directly with X-rays
- ITO coated transparent electrode were used as an anode & optical window



Outlook of the detector

[8] T. Fujiwara, et al., JINST, Vol. 8, No. 7 (2013)
[9] T. Fujiwara, et al., NIM A, 850 (2017)

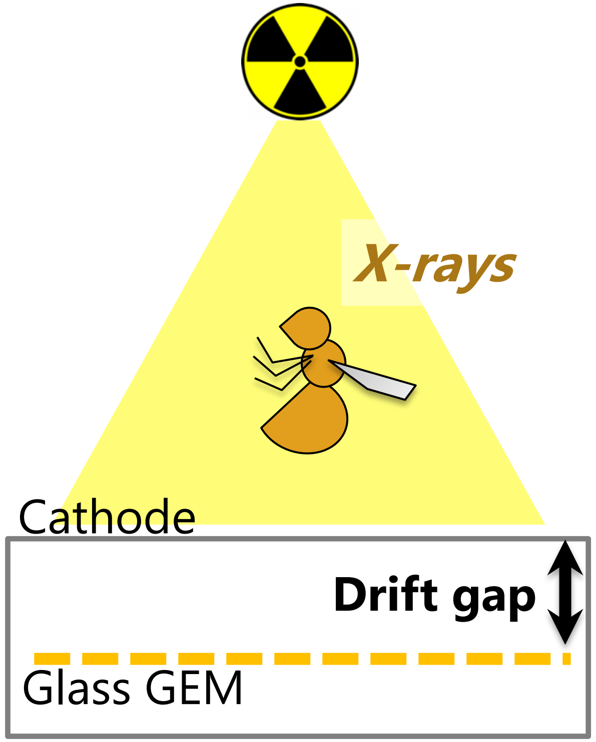
3. Optical readout Glass GEM (X-ray imaging setup)



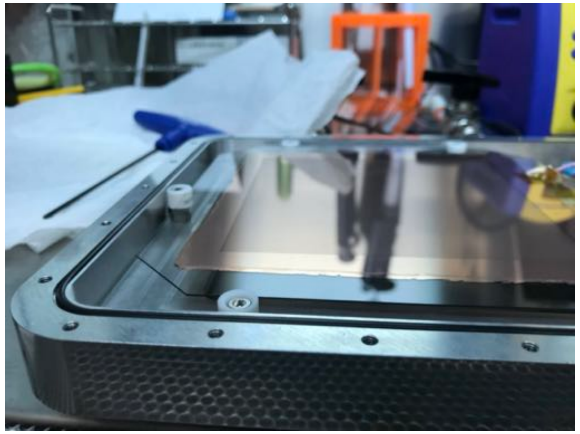
CMOS Camera
Hamamatsu
ORCA-Flash4.0 V3

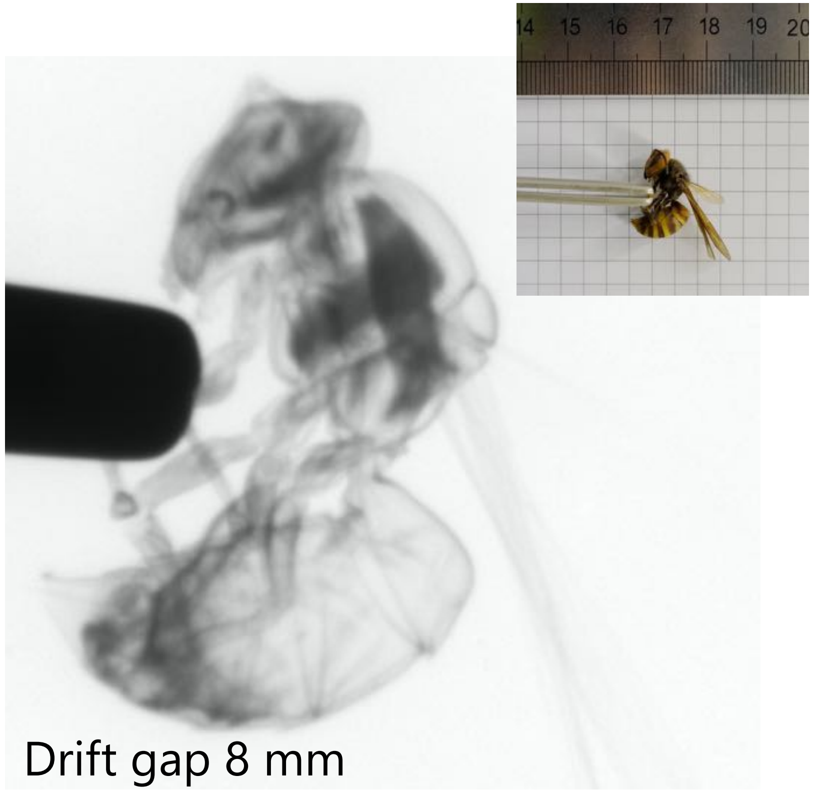
X-ray tube
Hamamatsu
L9631

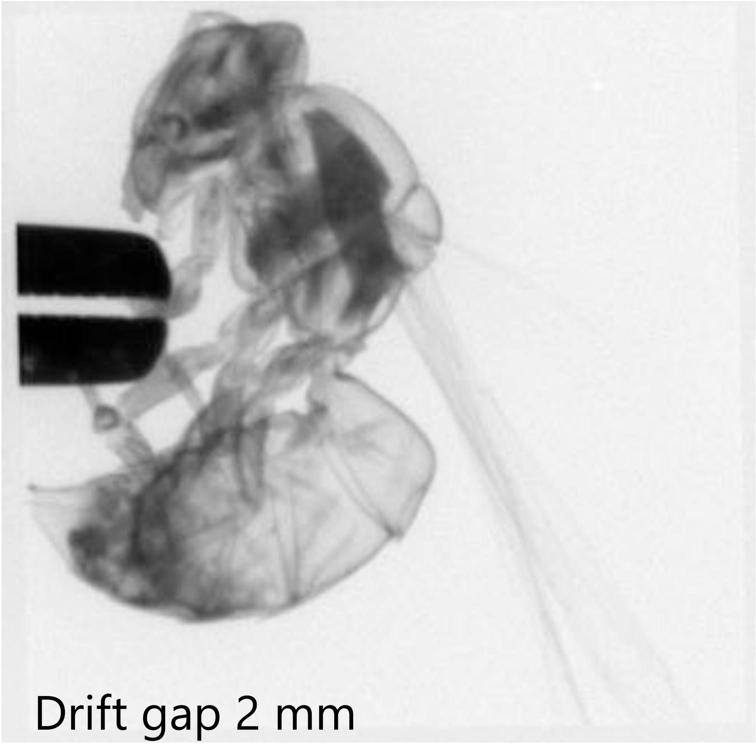
3. Optical readout Glass GEM - X-ray imaging

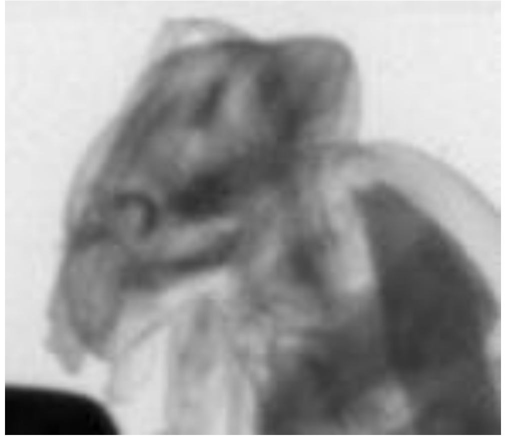


Gas chamber

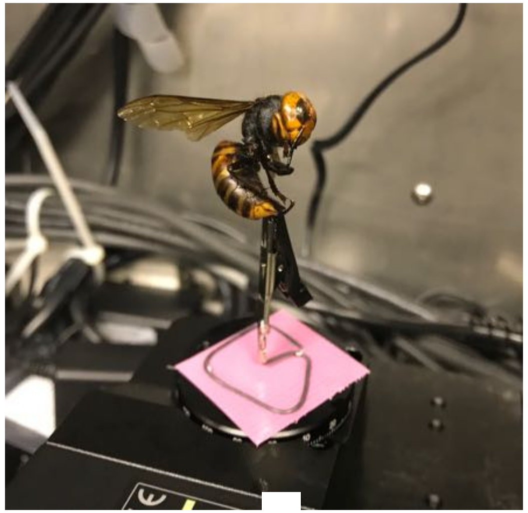




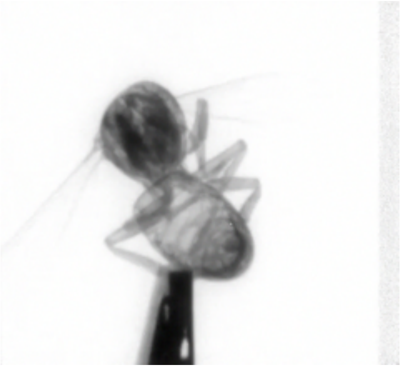




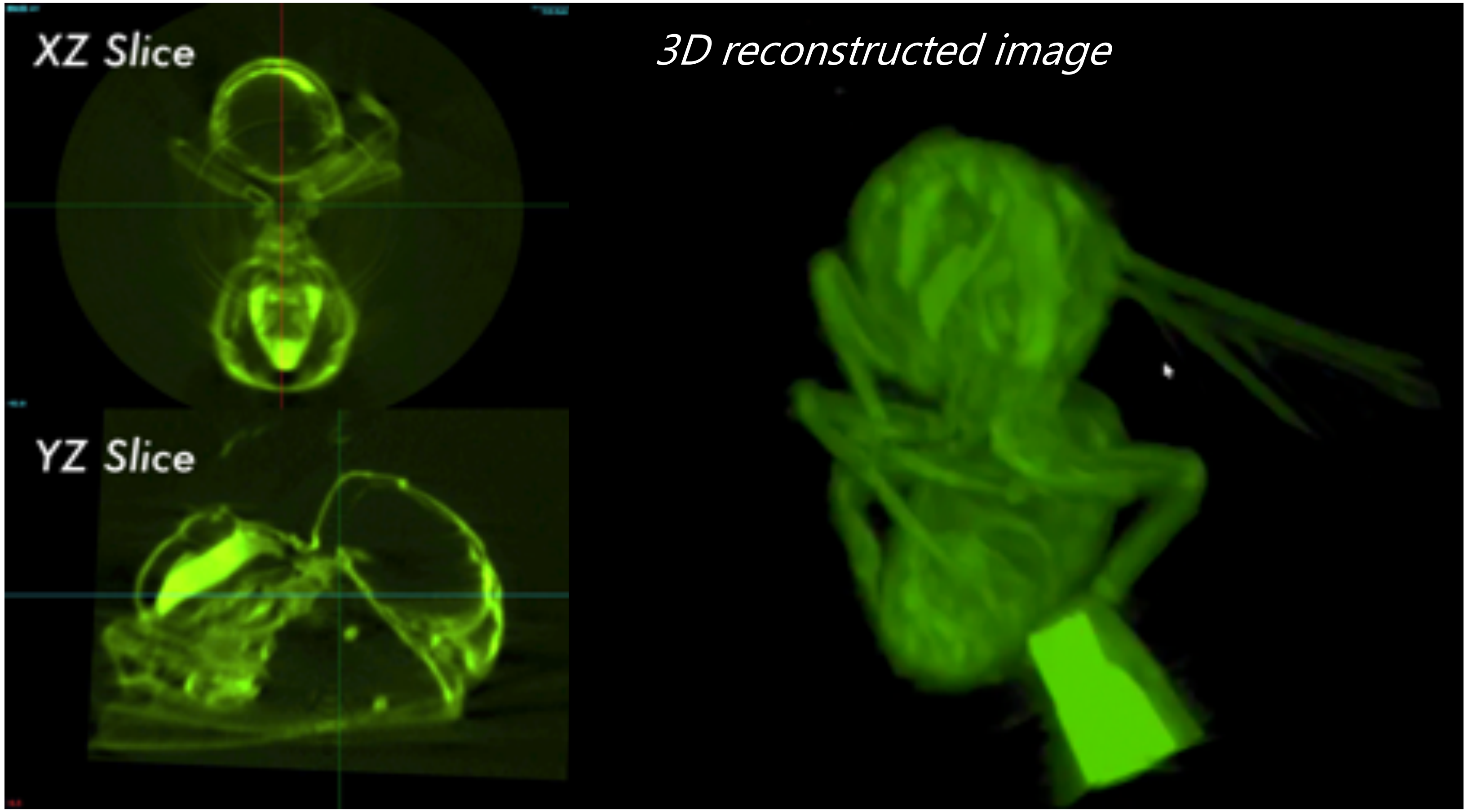
3. Optical readout Glass GEM - 3D X-ray Computed Tomography (CT)



Scanned object (a hornet)



360 rotated X-ray images (1 degree step)



Reconstructed 3D CT images

High resolution and high contrast X-ray 3D CT images of a hornet which consists of soft tissues were successfully reconstructed.

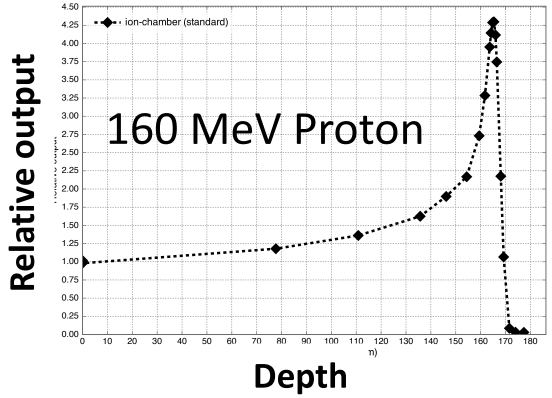
[10] T. Fujiwara, et. al, J. Inst. 14 (2019) P11022–P11022.

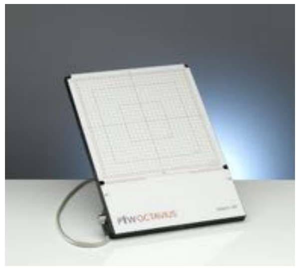
Dose Imager for Hadron Therapy

1. Background and motivation – what is the issue for dosimetry?

Conventional detector 1: Ion chamber

- Standard in clinical use
- Sharp Bragg peak is achievable
- Peak-to-Plateau ratio up to 4~5.
- **Spatial resolution is not enough (5mm)**
- **Takes time for each measurement**





Ion Chamber array

(5mm pixel)

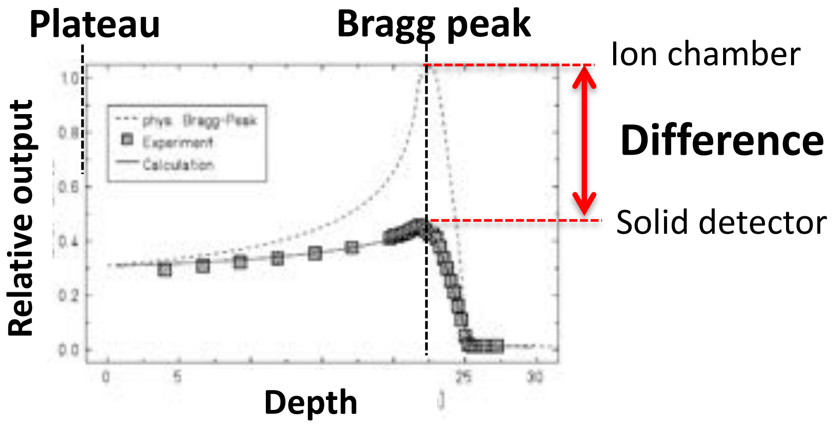
Peak-to-Plateau ratio

4.2 ~ 5.0

Proton/Carbon beam

Conventional detector 2: Solid detectors

- Great spatial resolution (films, imaging plates, scintillator screens, semi-conductors)
- Radiation hardness would be an issue
- **Saturated in Bragg Peak**



Peak-to-Plateau ratio

1.3 ~ 3.2

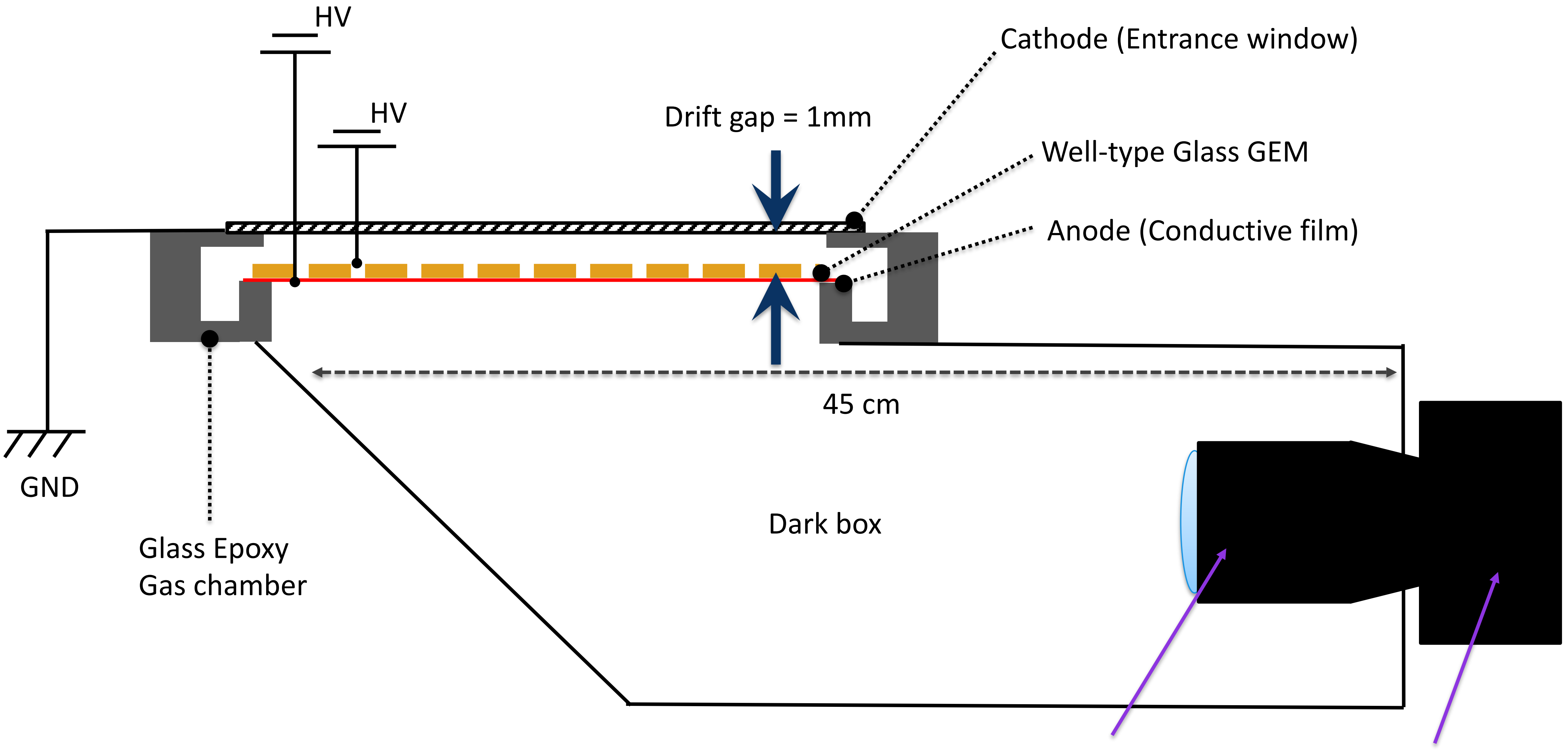
Proton/Carbon beam

Solid detectors has a quenching effect in high-LET radiation.

- Energy deposition density at Bragg Peak is larger than the density of luminescense center.

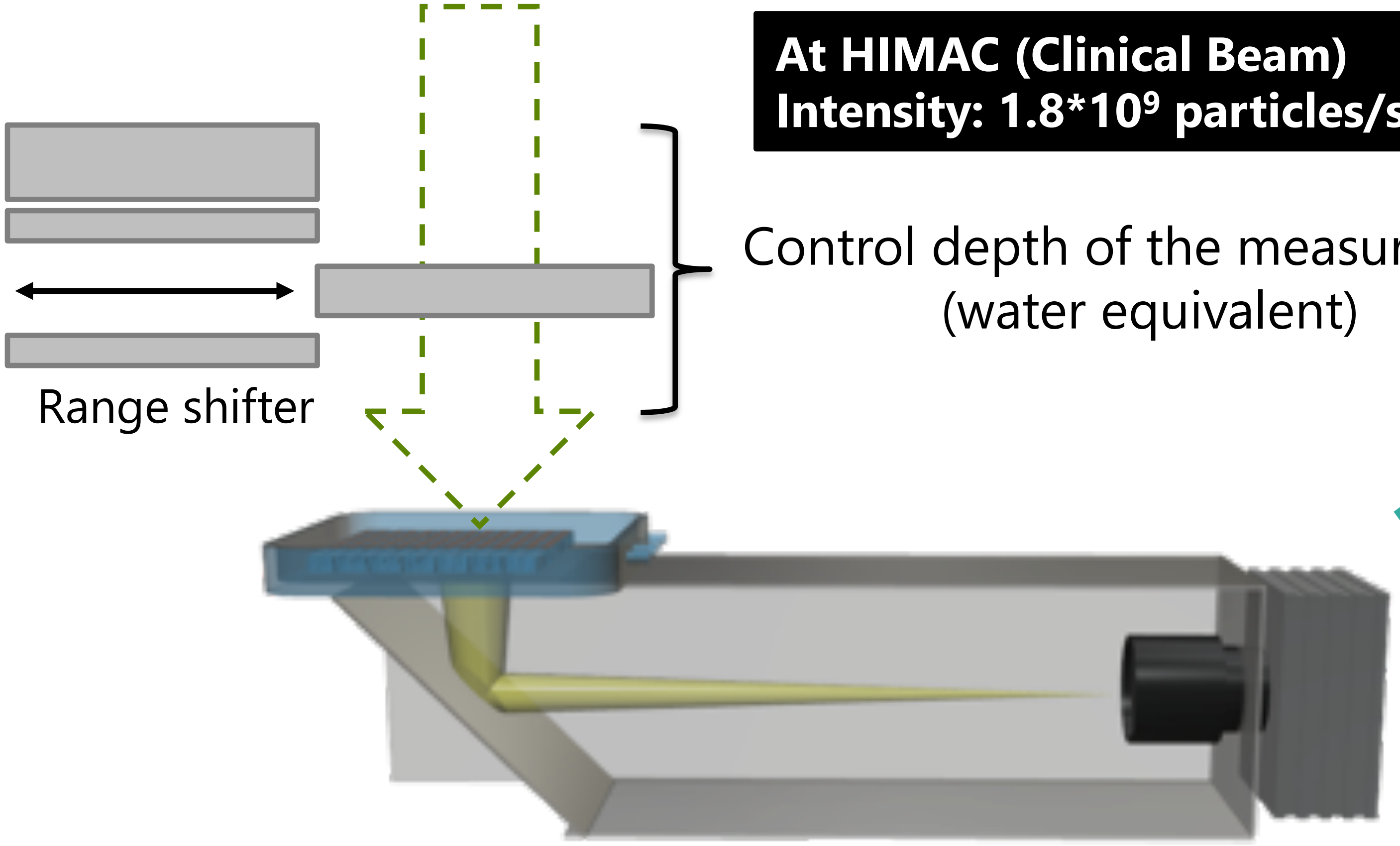
MPGDs have very little quenching effect and high spatial resolution

Detector construction (side view)



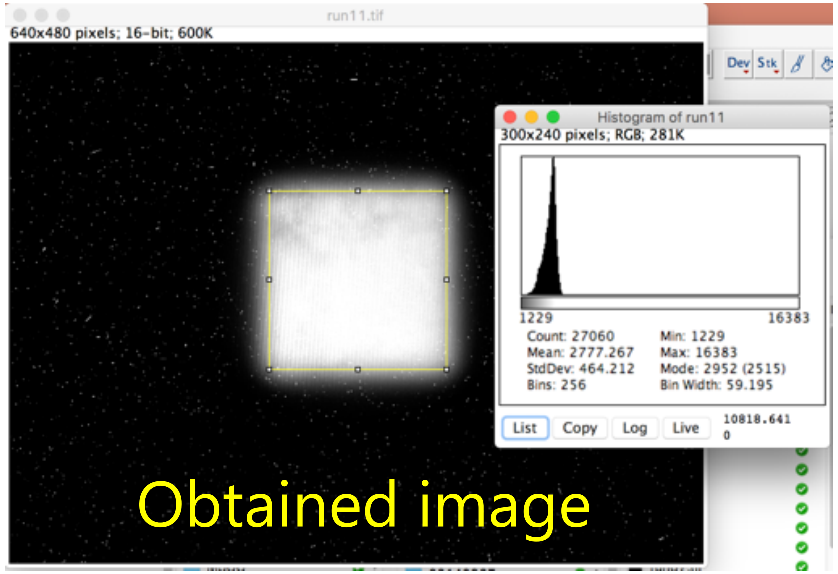
Updated to Brighter lens, high sensitive camera and shorter camera mount.

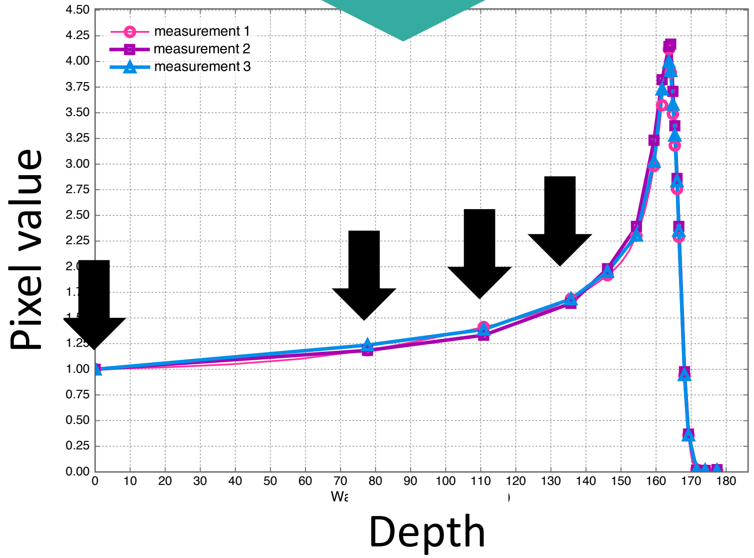
Experiment



At HIMAC (Clinical Beam)
Intensity: $1.8*10^9$ particles/sec

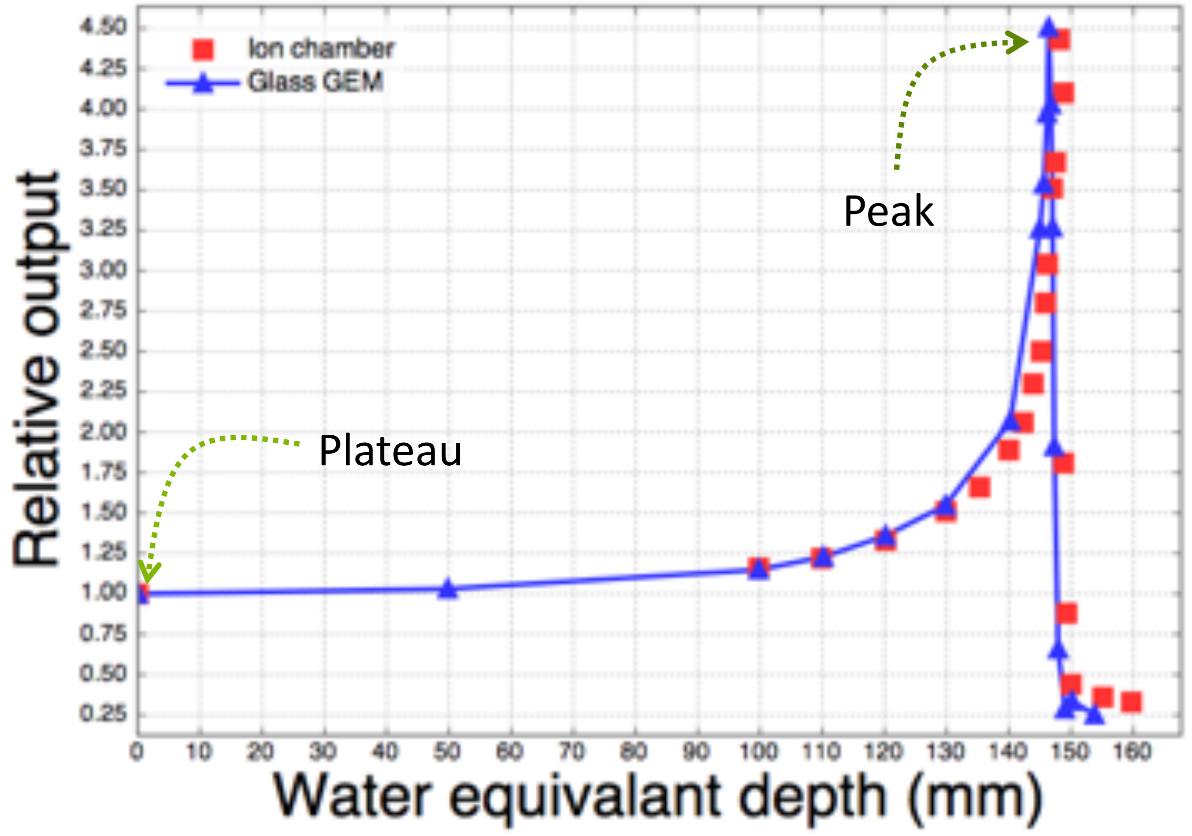
Control depth of the measurement
(water equivalent)

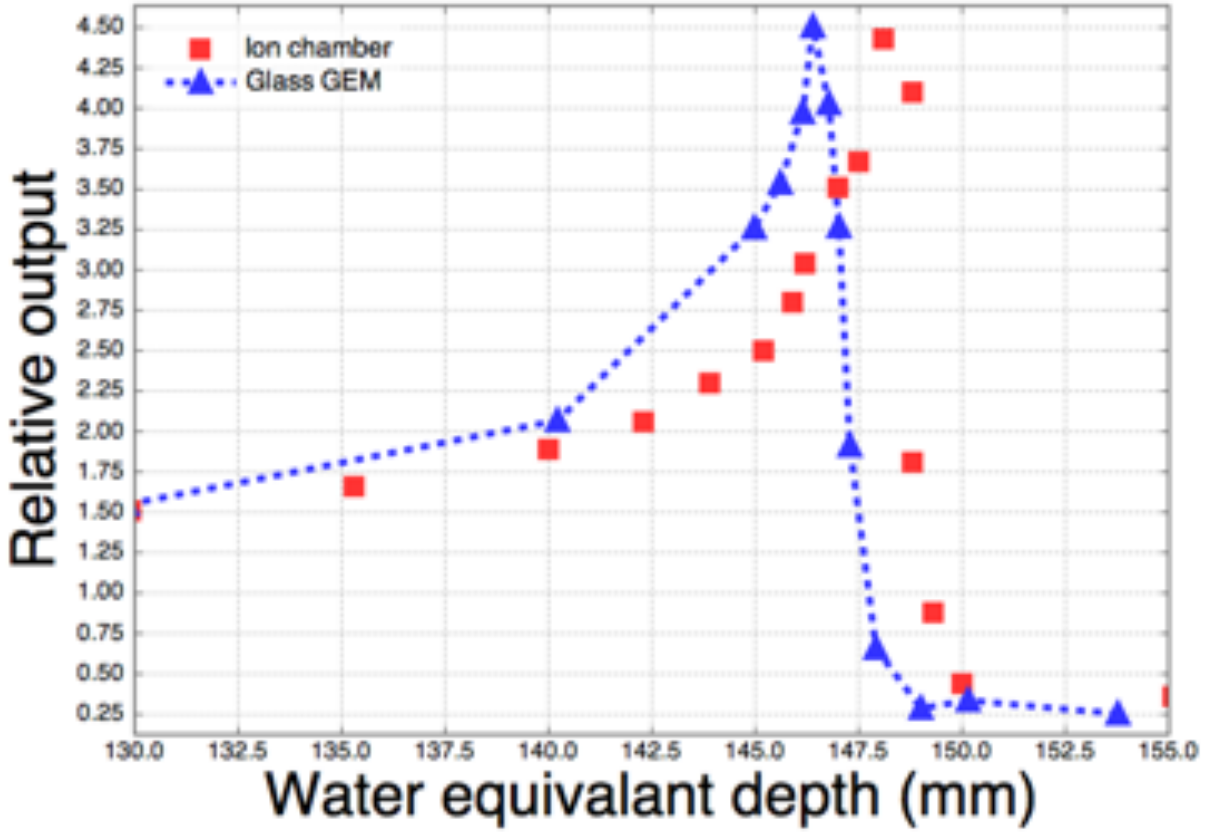




The pixel value of obtained image from CCD camera is plotted for each depth.

Results - 290 MeV/u Carbon beam mono-peak measurement

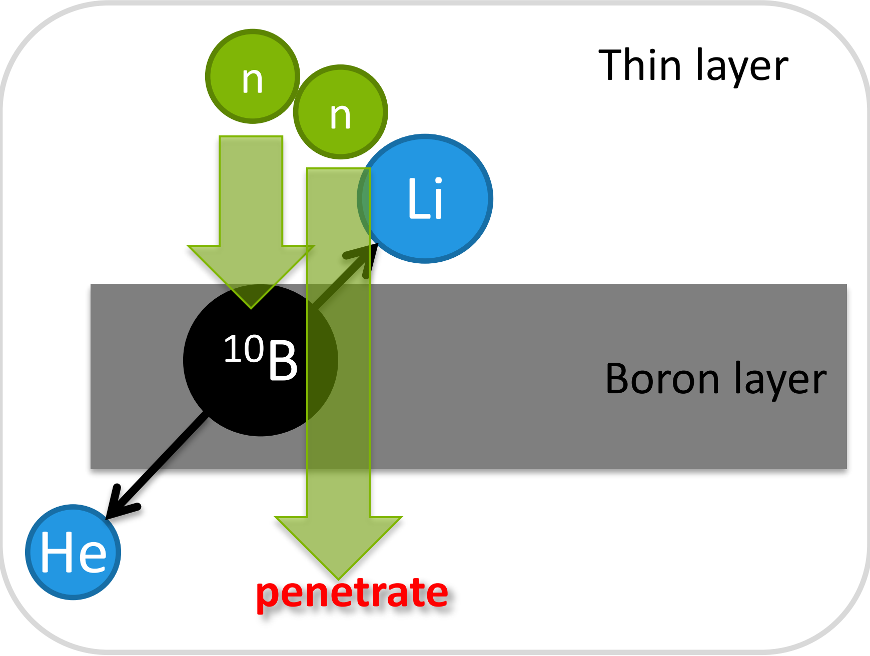


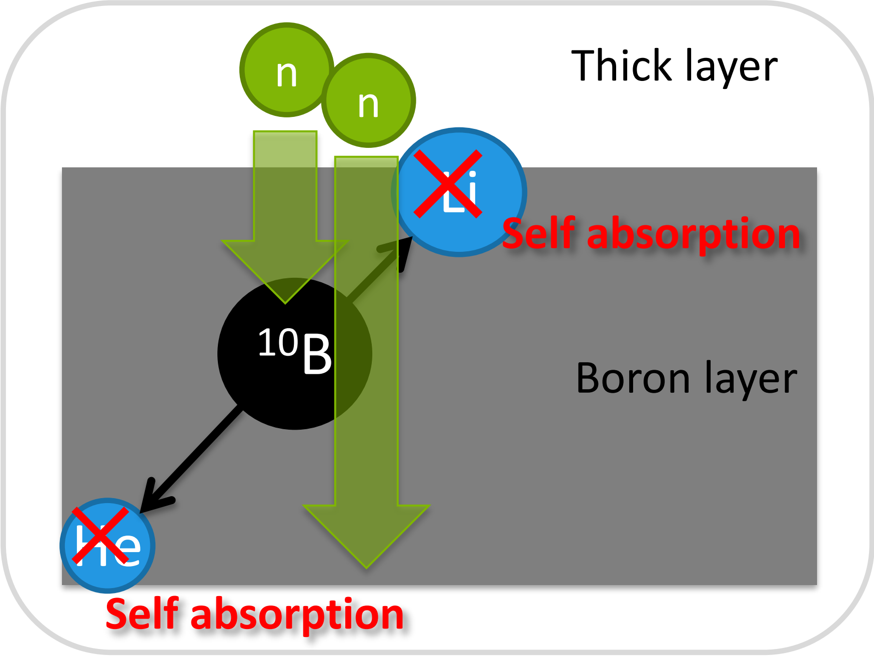


- Bragg curve of 290 MeV/u Carbon obtained with pixel values of CCD camera coupled with a scintillating gas-filled G-GEM chamber.
- **Peak-to-Plateau ratio was 4.48 (Ion-chamber), 4.51 (Glass GEM). (100.1%)**

Bragg-Edge Neutron Imaging Detector

Micro-structured Boron detector

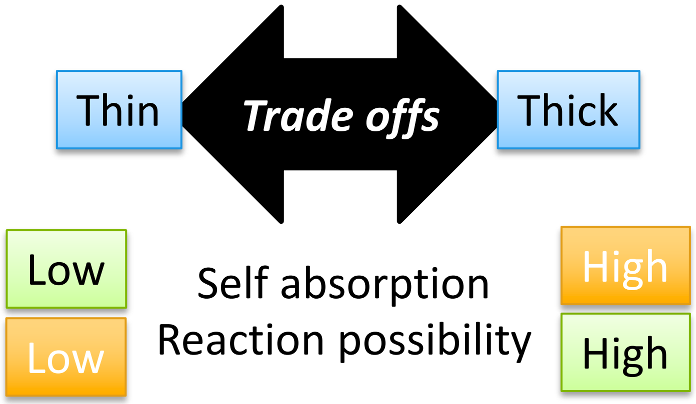




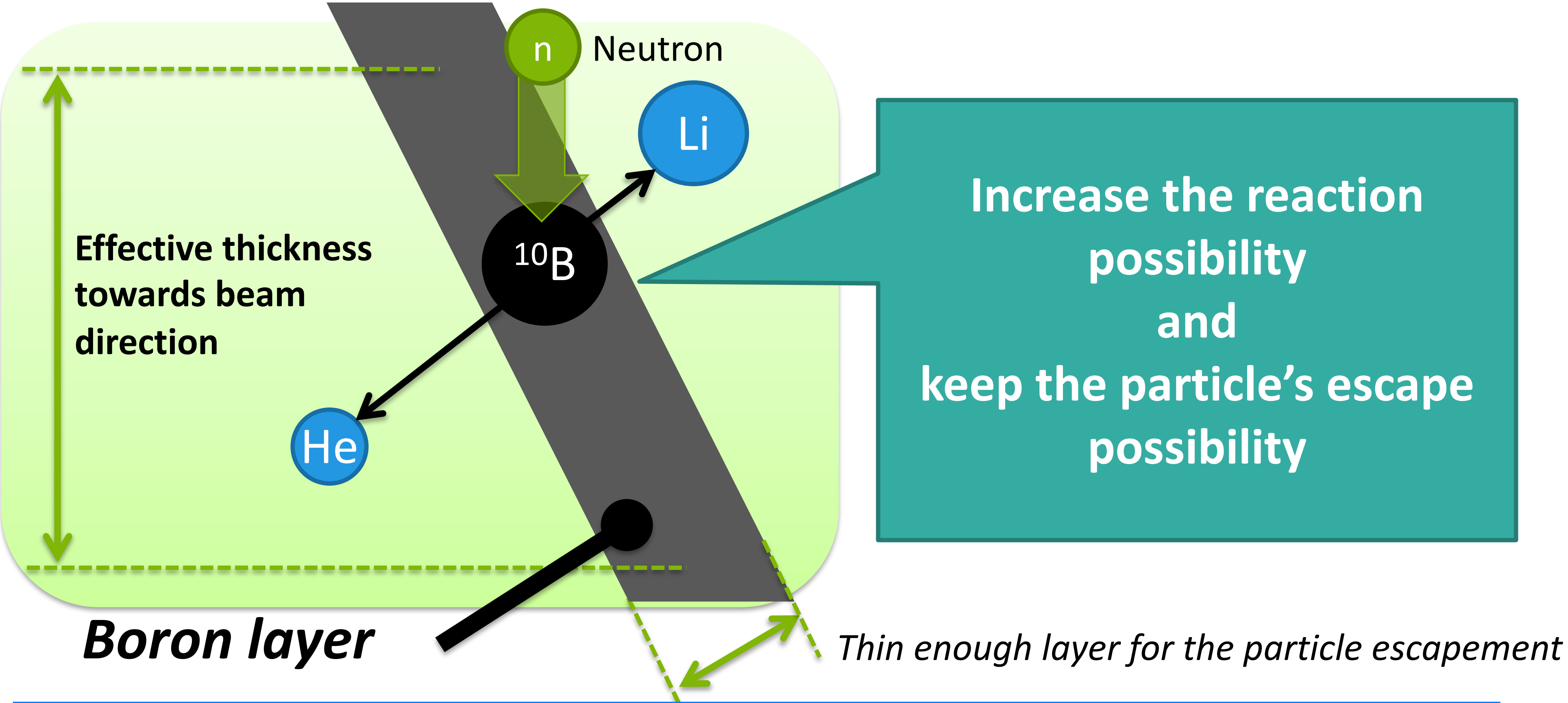
Reaction possibility -> Low
Self absorption -> Low

Reaction possibility -> High
Self absorption -> High

- B-10 are low price neutron converter
- Detect the charge from ionized α/Li particle
- Self absorption of the particle is an issue
- Charged particle cannot escape to counting gas

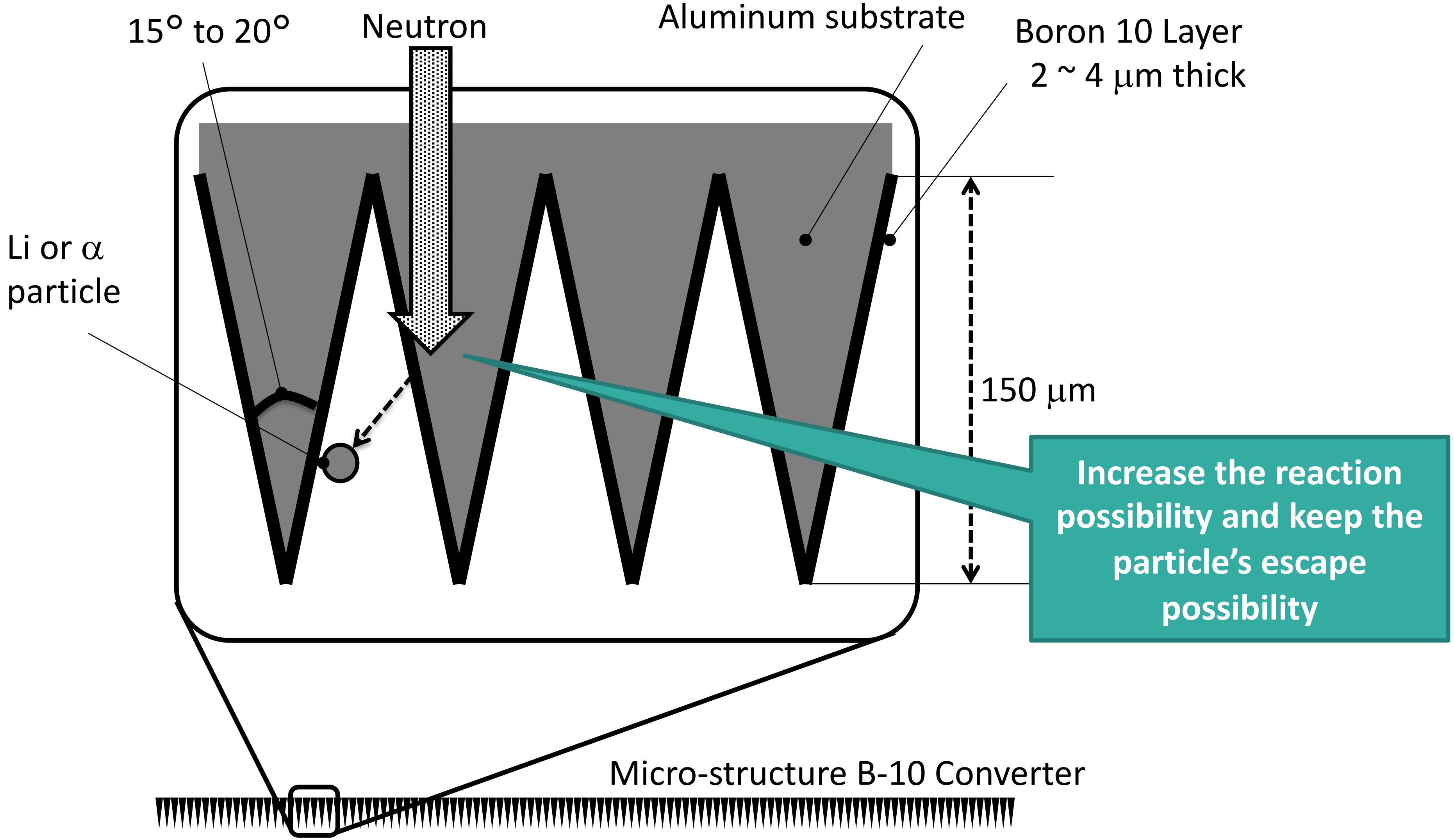


Micro-structured Boron detector



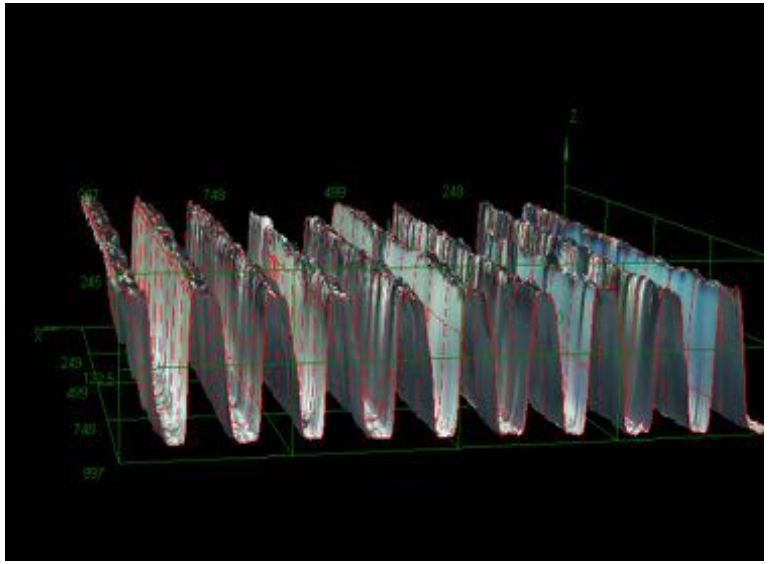
- Slanting the absorber layer towards the incoming beam
- Grazing incident angle allows a larger proportion of neutrons to be absorbed in the first few microns of the layer
- It results secondary particles have a higher probability of escaping into the counting gas.
- This leads to increase neutron detection efficiency.

Micro-structured Boron detector

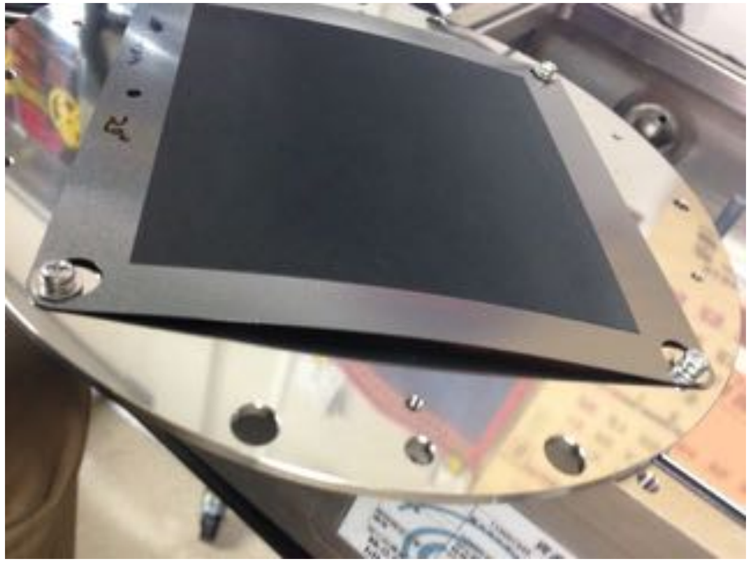


Micro-structured Boron detector

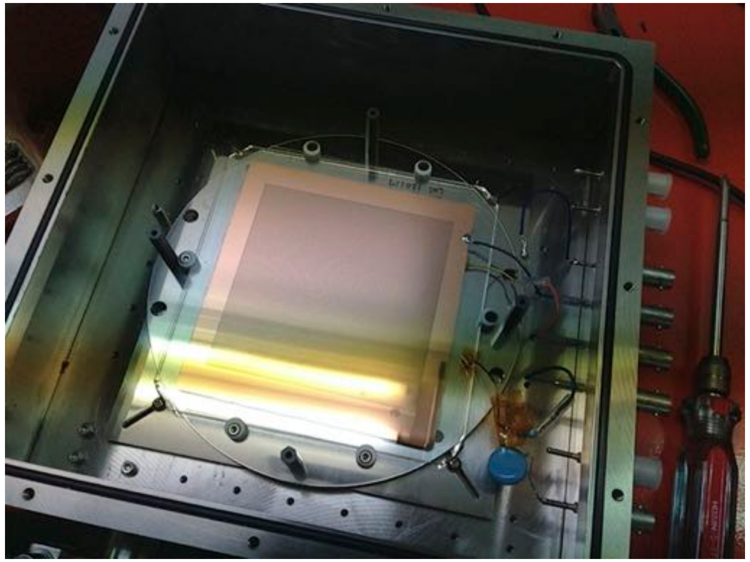
Micrograph of converter



3-D image

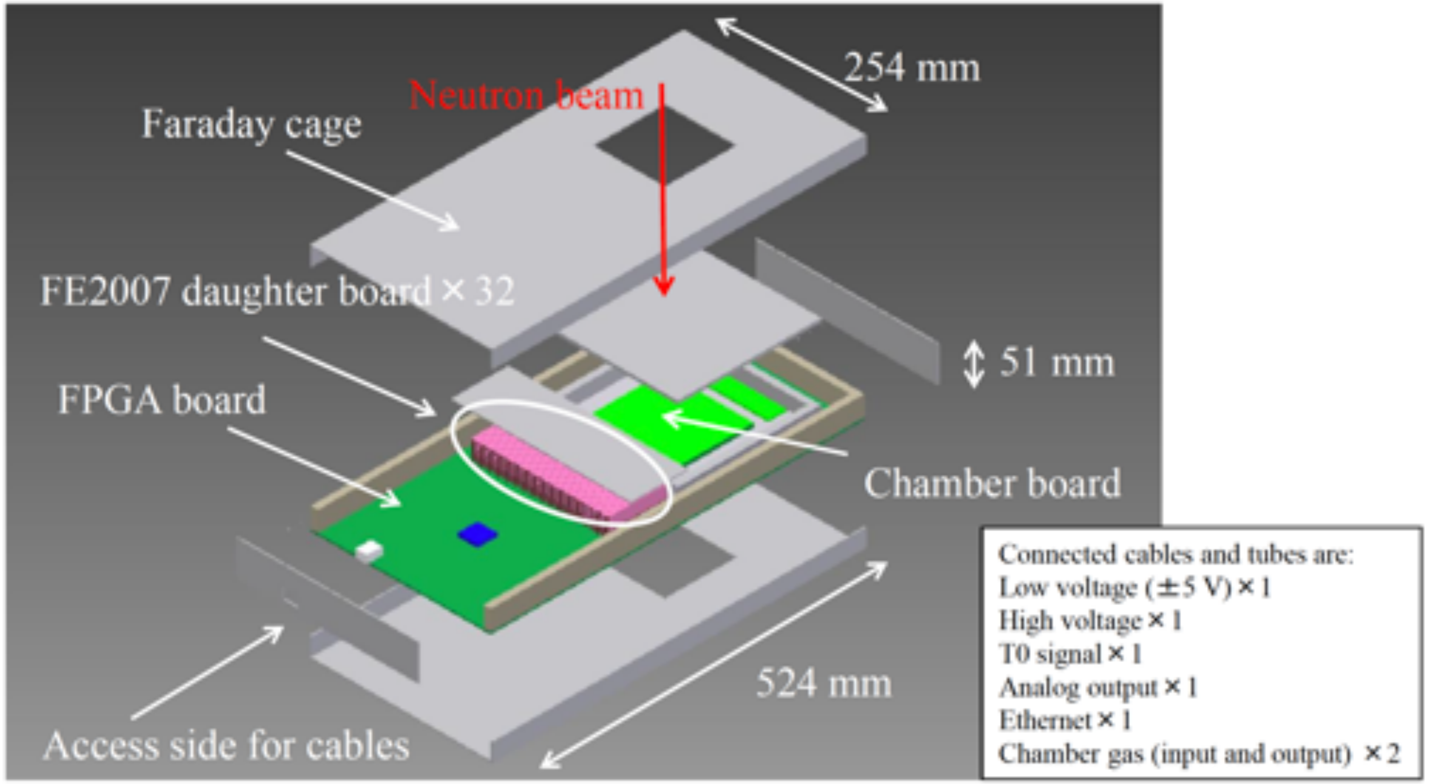


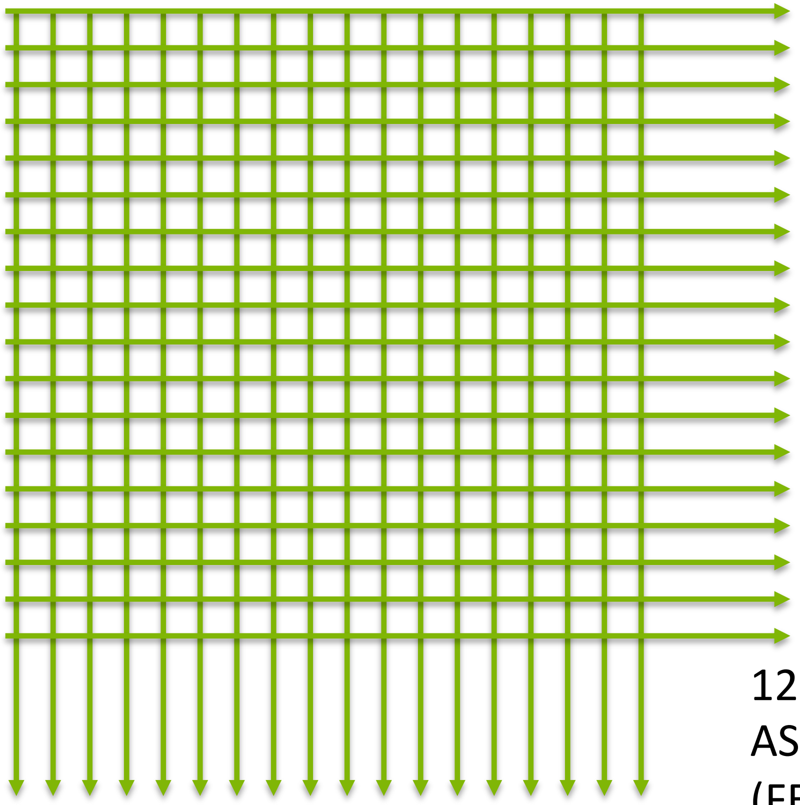
Picture of the micro-structure converter



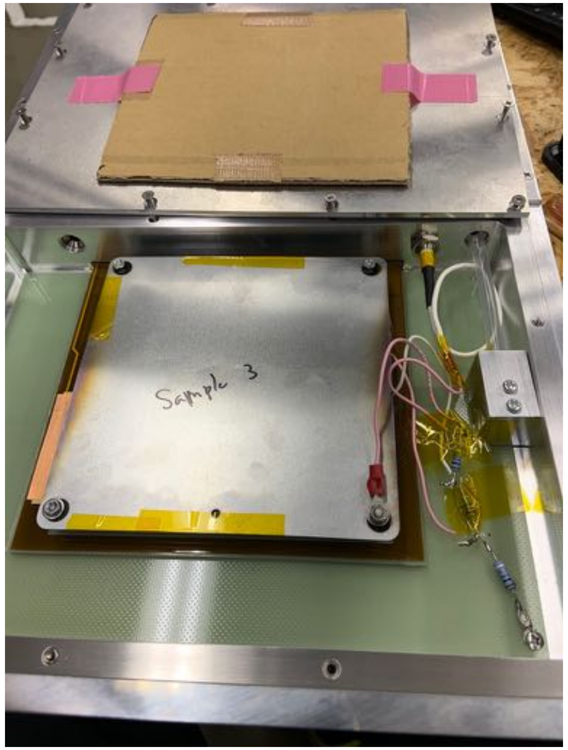
Glass GEM

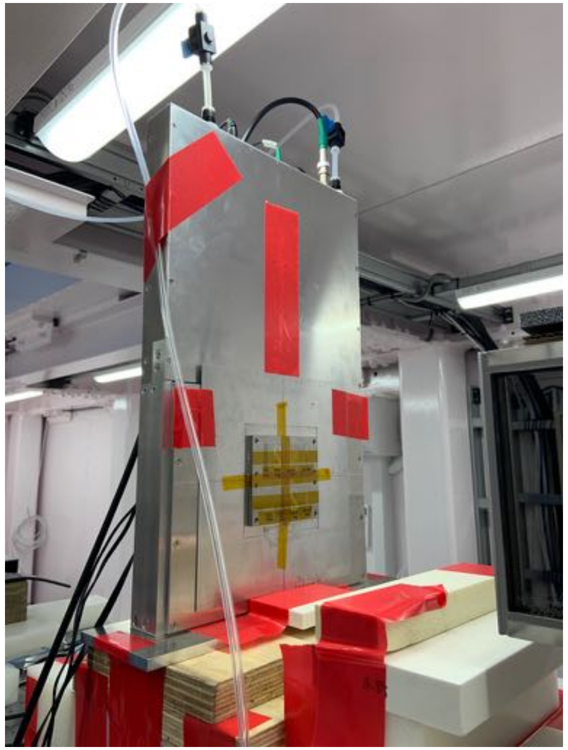
Readout design

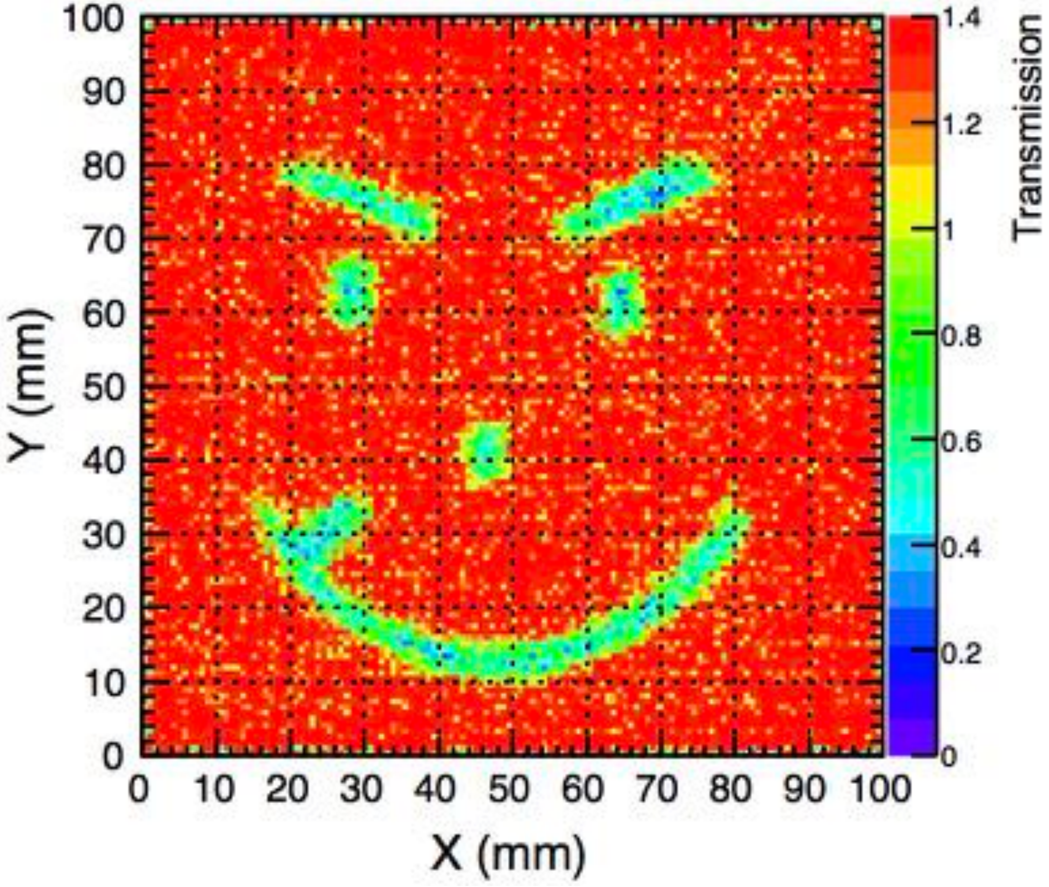




First neutron beam test at AIST

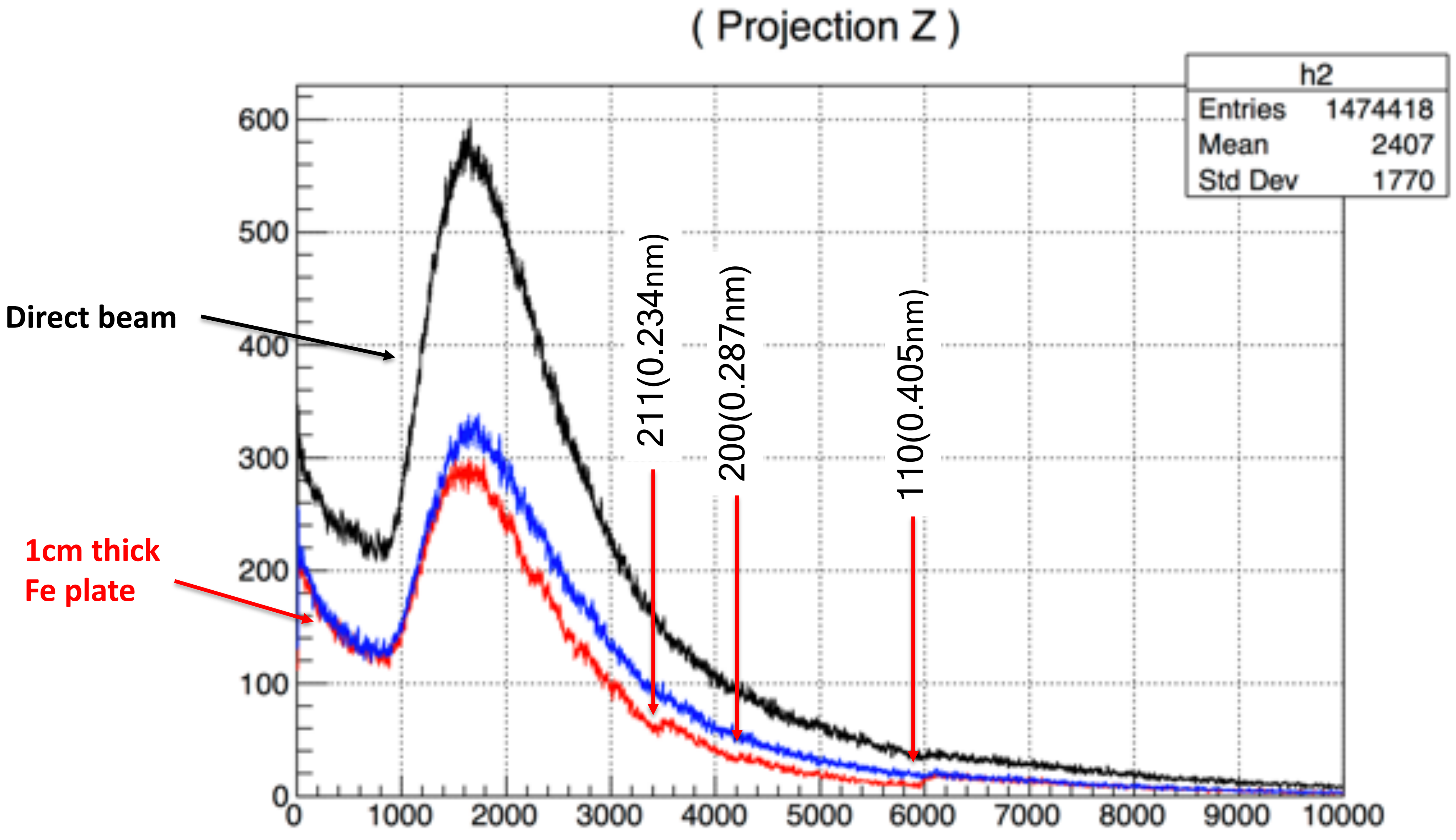






Spatial resolution =0.8mm (FWHM)

First Bragg-edge spectrum obtained with Glass GEM in AIST (Preliminary)



Summary

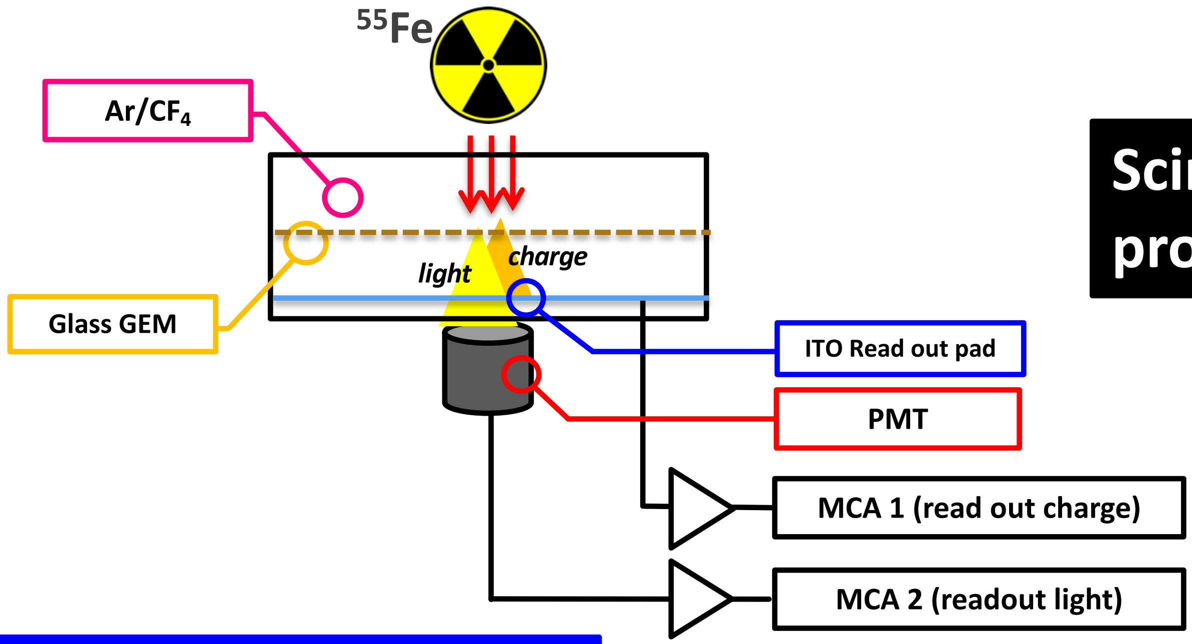
- Introduced the new fabrication process of Glass GEM
- **Application of Glass GEM detector**
  - X-ray imaging
  - Dose imaging detector for hadron therapy
  - Neutron Bragg-edge imaging detector

- Glass GEM is now open to everyone, and collaborators are always welcome

Thank you for your kind attention.

Backup Slides

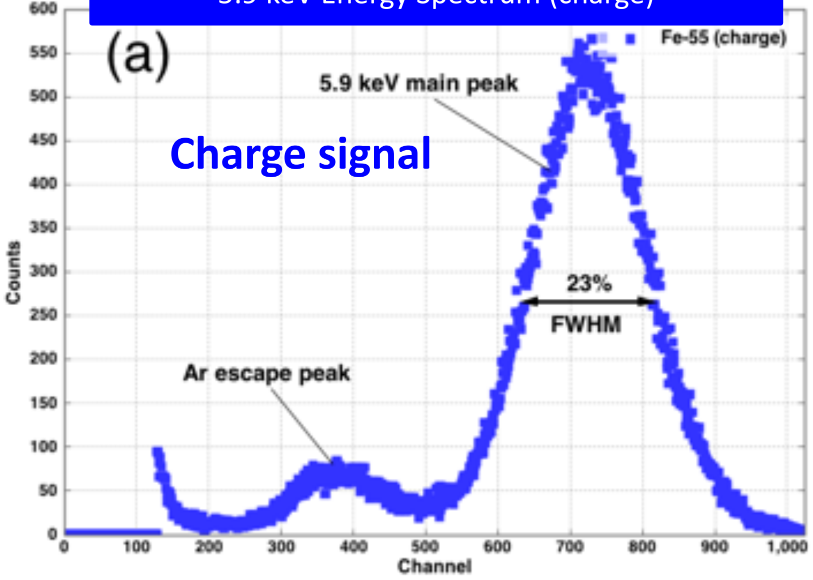
3. Initial experiment : 55Fe (5.9keV X-rays) & PMT [7]



Scintillation light from Glass GEM is proportional to charge

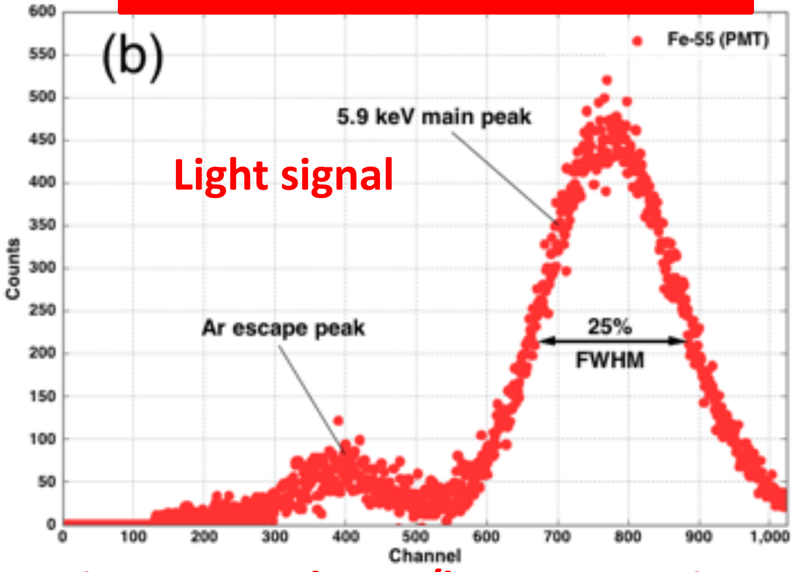
Charge and light measured at same time

5.9 keV Energy Spectrum (charge)



Good match

5.9 keV Energy Spectrum (light)



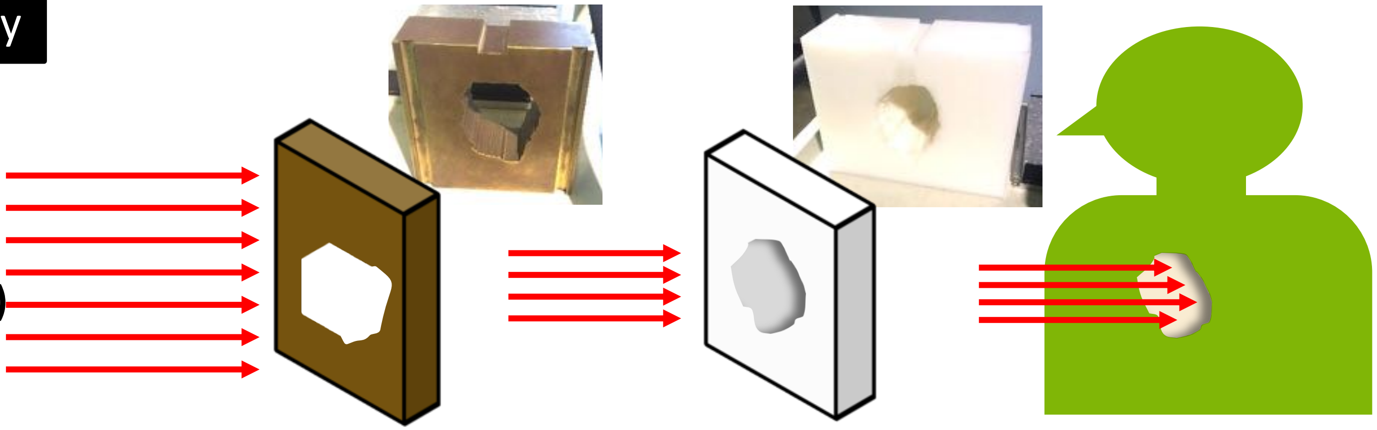
[7] T. Fujiwara, et al.,Jpn. J. Appl. Phys., vol. 55, no. 10 (2016)

Emits 85,000 phtons/keV @gas gain 9,000

1. Background and motivation – what is done in hadron therapy?

Hadron therapy

Hadron beam
(Proton/Carbon)



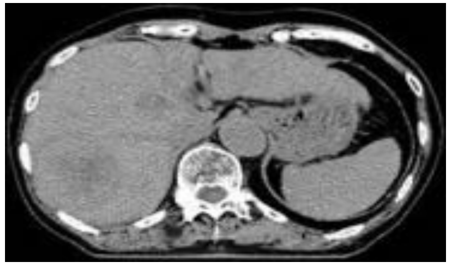
Collimator

Bolus (moderator)

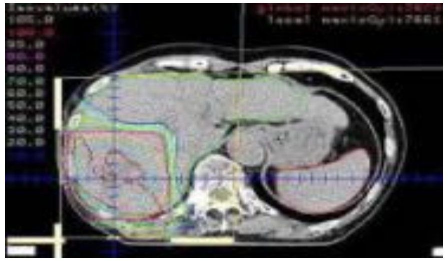
Personalized 3D dose formation is made with Collimator and Bolus for each patient.

Quality assurance

(1) X-ray CT



(2) Treatment plan



(3) Evaluation with dosimetry

(4) Treatment

Before the treatment, **quality assurance of treatment** is done with **precise dose measurement.**

Personalized dose is measured and <u>must be confirmed</u> that has good enough agreement with the treatment plan.